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SEWAGE SLUDGE TREATMENT FOR ENERGY PURPOSE IN CHINA

Waste Treatment in China

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SAVONIA UNIVERSITY OF APPLIED SCIENCES

THESIS
Abstract

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Abstract

This thesis is made for ANDRITZ China Technology to find out sludge incineration potential in China. ANDRITZ is looking for markets and customers for ANDRITZ sewage sludge incineration technology in China. In addition ANDRITZ China manufactures centrifuges, skeleton model filter presses, belt presses and rotatory drums to treat the sludge.

Sludge in China has become a major problem. It is considered to be toxic waste, because it contains pathogens, which are dangerous for human health. Therefore the disposal to environment as untreated waste sludge has caused severe damage. China government has stricken sludge disposal regulations in order to protect environment and water resources.

The thesis is divided to wastewater basics, sludge treatment methods, sludge treatment apparatuses, China government vision about sludge treatment and future views. The thesis aims to give information about sludge business, governmental status and supporters. The thesis includes alternative sludge disposal methods and compares them in order to find the best possible situation for sludge incineration in China. There is an estimation the sludge business begins rapidly growing in few years, but sludge incineration is still big question. The best sludge processing methods and answers for future sludge treatments depend on government's regulations.

Sludge incineration causes air pollution and landfill area scarcity makes it more attractive method to dispose sludge with combustion technology. Landfill as sludge disposal method is causing emission problems to soil and water resources. The Chinese government is responsible for controlling of sludge disposal, which is the most desirable way to protect environment by alternative sludge treatments enforcements.

Furthermore studying sludge energy markets and researching them; this thesis includes a proposal for a patent in China. The patent information and details are not listed or shown in this thesis; the blank area contains secret classified information which hinders a person to read any details.

Keywords
Sludge, wastewater, treatment, China, MOHURD, MEP, MOEP, NDRC, FYP

FOREWORDS

I appreciate the opportunity to complete Bachelor's thesis in 安德里茨 ANDRITZ ATC KFT/KRP division. ANDRITZ China Technologies KFT/KRP team have been helpful and supported in difficulties such as in Chinese language and contacting with different wastewater plants. I would like to give special thanks to my ANDRITZ supervisor Mr. Markku Lehtinen for supporting, believing in my high motivation, working and learning capability. Without him, I wouldn't be in Foshan 佛山市, Guangdong 广东省 province. I thank my supervisors Mrs. Ritva Käyhkö and Mr. Harri Heikura from Varkaus, Savonia University of Applied Sciences for supporting me and giving advices in order to complete this thesis.

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ABBREVIATIONS

AD	Anaerobic digestion
BFB	Bubbling Fluidized Bed
BOT	Build-Operate-Transfer
BTU	British Thermal Unit
BTU/lb	British Thermal Unit in one pound
CFB	Circulating Fluidized Bed
CNY	Chinese Yuan, money and currency in China
CPC	Communist Party of China
DAF	Dissolved air flotation
DS	Dry solids
EfW	Energy from Waste, also known as Waste to Energy
FYP	Five year plan
GWh	Gigawatt hours, 1.0×10^{-6} gigawatt hours
HSO_3	Bisulfite
IWM	Integrated Waste Management
kg	Kilogram, a metric unit for weight. One kilogram is one thousand grams
kWh	Kilowatt-hours is an energy equivalent 1kW of power expanded for one hour
lb	Pounds, one 1lb = 0.45359 kg
m^3	One cubic meter equals 1000 liters of water
MC	Moisture content [%]
MEP	Ministry of Environmental Protection, P.R.China, also known as MOEP
MJ/kg	Mega Joules in Kilogram, a heat value
MOHURD	Ministry of Housing Urban-Rural Development
MSST	Municipal Solid Sludge Treatment
MSWM	Municipal Solid Waste Management
MWS	Municipal Waste solids
Na	Sodium
$NaHSO_3$	Sodium-Bisulfite
NDRC	National Development and Reform Commission
NO_X	Nitrogen oxide
PRC	People’s Republic of China and known as P.R.China
PS	Primary sludge

RMB	Renminbin, money and currency in China
SD	Solid density, solid parts in sludge
SO_2	Sulfur dioxide
SO_X	Sulfur oxide
TWH	Terawatt hours, 1.0×10^{-9} terawatt hours
USD	U.S. Dollar, United-States of America
UV	Ultraviolet
WAS	Waste activated sludge, also called secondary sludge
WtE	Waste to Energy
WWP	Wastewater plant

1 INTRODUCTION

This thesis is divided to the engineering and business sections. The Engineering is Energy and Environmental section in sludge treatment aspects and the business is People's Republic of China governmental and business aspects. The Energy and Environmental part contains the basics of wastewater system, wastewater sludge management, treatment and incineration with sludge disposal methods. There are calculations about the sludge volume change compared to the sludge moisture content change. The Engineering part contains information about different separation, dewatering and thickening methods, comparing them in order to find most efficient and easy method to treat sludge. The Engineering section contains also sludge disposal methods and comparison, which is the least and the most attractive disposal way. The incineration is one of them and ANDRITZ is looking incineration potential in China. Incineration and different incineration methods are explained on page 30.

In the business section the volume changes of sludge are used to calculate further sludge treatment possibility whether sludge is incinerated in China. The government, business and different stakeholders that affect sludge markets are introduced at the end of this thesis. There are some governmental aspects about sludge disposal methods, which are the most and least attractive ways to dispose sludge. The government highlights sustainable development and environmental friendly future in order to reduce coal incineration in China. The governmental section also includes emission and sludge disposal regulations, but the future of sludge treatment is unknown. The next Five-Year plan will be implemented between 2016-2020 and that is containing People's Republic of China's supporting plan for emission reduction and sludge disposal. The Business section introduces old and current projects by economical or financial failures and highlights of sludge disposal. Those projects can be evaluated to find the best solution in sludge disposal and incineration.

2 ANDRITZ GROUP

The ANDRITZ GROUP is a globally leading supplier of plants, equipment, and services for hydropower stations, the pulp and paper industry, the metalworking and steel industries, and solid/liquid separation in the municipal and industrial sectors. In addition, ANDRITZ offers technologies for certain other sectors including automation, the production of animal feed and biomass pellets, pumps, machinery for nonwovens and plastic films, steam boiler plants, biomass boilers and gasification plants for energy generation, flue gas cleaning plants, plants for the production of panelboards (MDF), thermal sludge utilization, and biomass torrefaction plants. (ANDRITZ Oy 2015.)

ANDRITZ provides tailor-made plant, system, and service solutions to customers in China. Established in 2002 with over 1,600 employees currently, ANDRITZ (China) Ltd is a 100% ANDRITZ GROUP owned company which supplies technologies and solution for the group four business areas: Hydro, Pulp & Paper, Metals and Separation, also for many other industries and products. Dedicating itself to bring the ANDRITZ Group's state-of-art technologies to China and provide superior service to its large local customer base. In addition to the manufacturing centers in Foshan Chancheng and Sanshui districts, several branch offices have been set up in Beijing, Shanghai, Chengdu and Hangzhou. The area of Foshan workshop already exceeds 68,000 sqm today. (ANDRITZ ATC 2015.)

3 THE BASICS OF WASTEWATER TREATMENT AND WASTEWATER SEWAGE SLUDGE

In this chapter wastewater treatment will be seen in different treatment phases and how it is done. In wastewater treatment there are two different ways to handle process. One is the water in wastewater treatment, known as watering part of the liquid. The second part is the solid part, known as dispense of water in sludge treatment.

In liquid part the wastewater travels from preliminary treatment to primary treatment. These two treatment methods are mechanical treatments. Then wastewater continues to secondary treatment which is biological treatment. The last wastewater treatment is tertiary treatment which is also chemical treatment. Finally, clean water is released to streams. (SSWM, 2014.)

3.1 The Basics of the Wastewater System

Like in any kind of wastewater system, the person must know the process and all contamination in the water. The water is collected from public channels conveyed by big pipes to wastewater hall supplies. Smaller pipes convey water from storm basin and from hall supplies to pump station and pump station will pump it to the first round of treatment which is called preliminary treatment. The first treatment is called preliminary, second treatment is primary, then follows secondary and finally tertiary treatment takes a place. Different treatment phases are shown in Figure 1. (SSWM, 2014.)

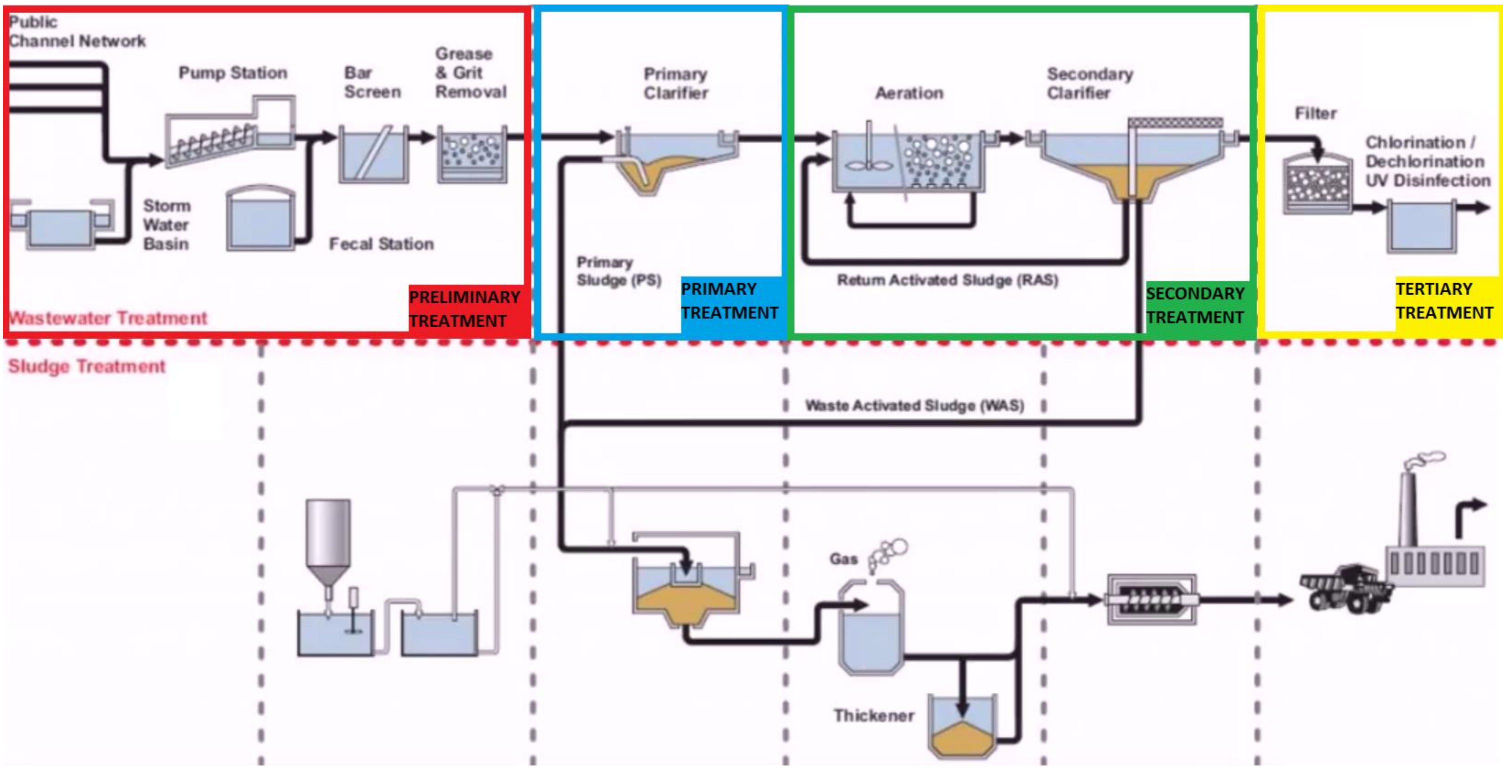


Figure1. Preliminary, primary, secondary and tertiary treatment in WWP (wastewater plant). (The original picture is shown in Appendix 6.)

Preliminary treatment is all mechanical treatment and in many wastewater treatment plants preliminary and primary treatments are fused together, which is called primary treatment. In primary treatment physical apparatuses are used for separating particles mechanically from the water, because collected water contains solid parts as well as liquid parts. The liquid parts have nutrient sources, because the wastewater contains human waste. That means the water contains protein products, carbohydrates, sugar products and grease products. (SSWM, 2014.)

3.2 Mechanical Treatment

3.2.1 Preliminary Treatment

There are many different solids toilets flush down and which can be collected and separated from water by preliminary treatment, also called mechanical treatment. In preliminary treatment bars and screens are used to screen huge solid elements from water. The second phase in mechanical treatment is grease and grit removal. In this treatment gravitational force is utilized to separate materials. For example, fat materials and grease materials are not soluble and will float on the water, if they have given time for settling down. The collected grease and fat solutions passed through the bar's screens can be coagulated in the tip of screening system. In the tip grease balls formation will float and these grease balls need to be scrapped and scum removed. The end result is water where all small particles of the nutrient sources stay in liquid form. The bigger particles are removed in the bar's screens and in grease removal system. (SSWM, 2014.)

3.2.2 Primary Treatment

Basically in primary treatment, there is one large base which is called a primary clarifier. This clarifier has one centerline, one strand "layer" on the top and one strand on the bottom. Both strands are functioning in different ways. For example, the top strand which is moving on the surface of the water is dilating all small particle materials. Those small particles are flocculating on the water and they are dragged to one side by keeping them away from the non-dilated particles. The second strands are also rotating but in very slow velocity. This rotation helps all small particles to sediment in low region or in lower tank in this primary clarifier (see Figure 3.) The sedimentation phase. The sediment material is called primary sludge, where sludge means the solid waste part of the wastewater treatment. (SSWM, 2014.)

3.2.3 Filtration

Wastewater filtration is consisting of two parts: The liquid part and solid part. The solid part is soil which can be easily separated using preliminary treatment like bar screens and grease removal. The second part is small particles that are removed in the secondary part of primary treatment. The particles require sedimentation time by utilizing gravitational force to gather as bottom sediment. After sedimentation grease is removed and what is left is sludge. This sludge is directed to sludge treatment process. Figure 2. illustrates sludge conveying to the sludge digestion process. (SSWM, 2014.)

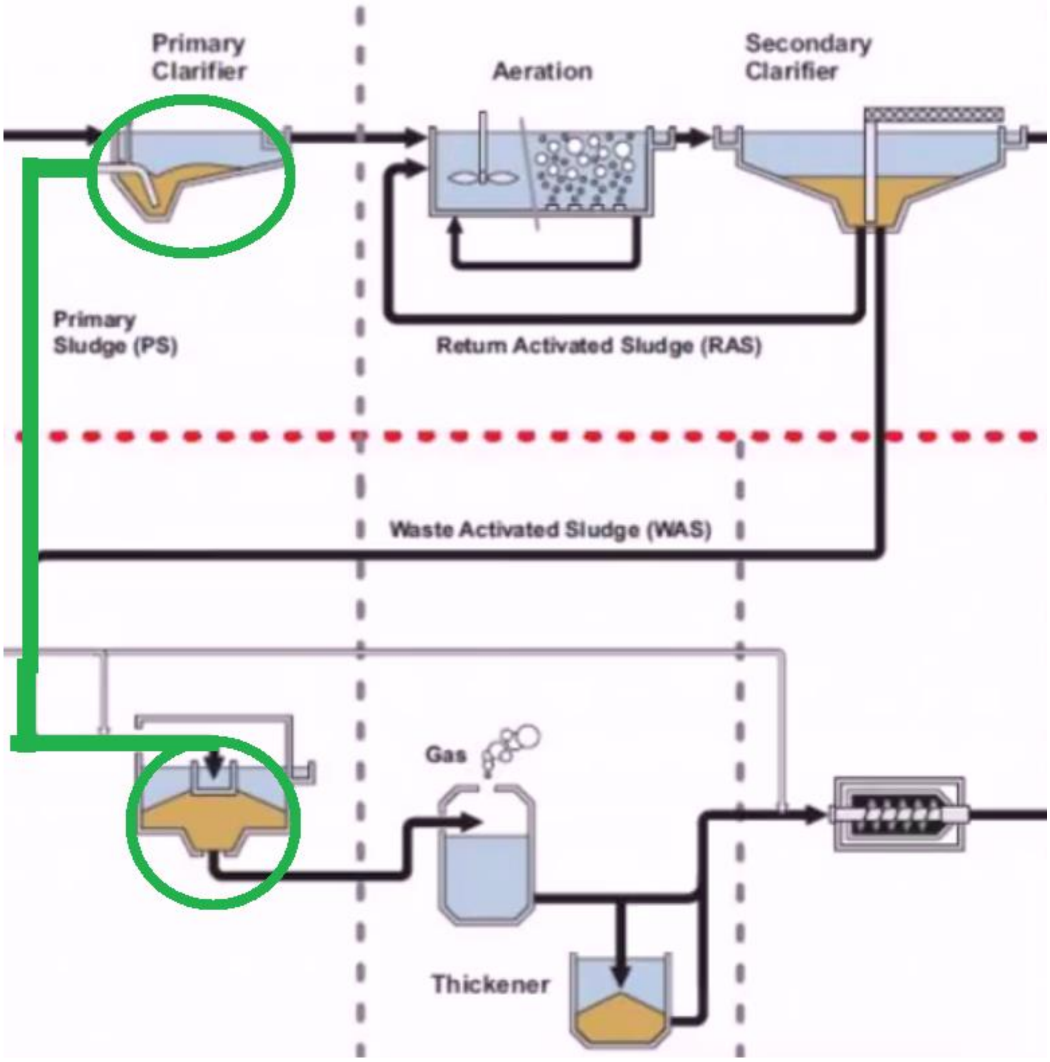


Figure 2. The primary sludge (PS) is directed to the sludge treatment process. (The original picture is shown in Appendix 6.)

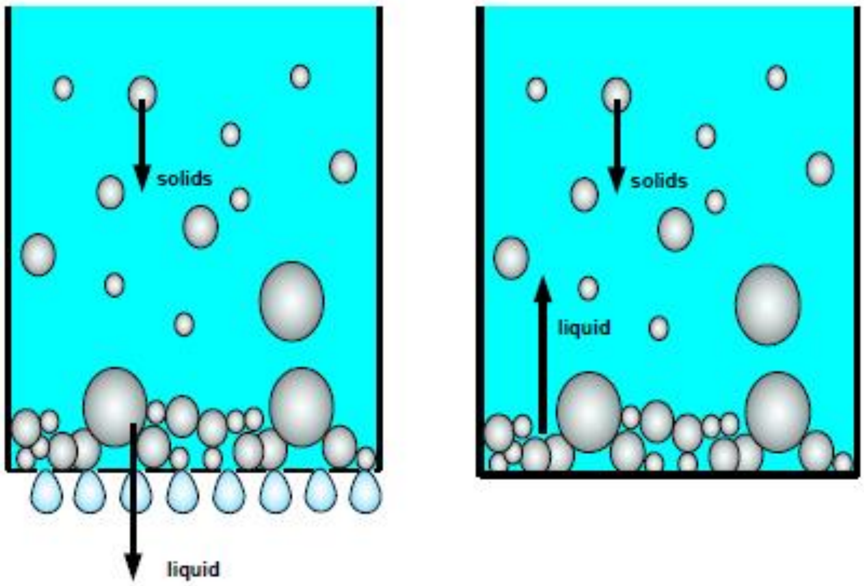


Figure 3. From left to right: Filtration, Sedimentation. In filtration: solids and liquid move in same direction. In sedimentation: solids and liquid move in opposite direction. (ANDRITZ Centrifuge PDF. 2014.)

3.3 Biological Treatment

3.3.1 Secondary Treatment (Primary Clarifier)

The cleaned water from the primary clarifier is directed to second round, which is called the secondary treatment of wastewater treatment. This treatment is part of a biological treatment, where microorganisms purify water. There are two different phases; the first in an aeration basin and another in an anaerobic chamber. Water from the primary clarifier is lead to the aeration basin, where a propel or a fan will vigorously aerate the basin all the time. Adding the air in the basin will help bacteria to grow in the water by multiplying very rapidly. Those bacteria will eat most of the nutrients, which are stored in this wastewater, because wastewater is consisting human waste. The bacteria are fed by this method and a certain type of bacteria has to be selected, because the bacteria must be able to survive and multiply in condition which contains a lot of air and liquid. (SSWM, 2014.)

3.3.2 Secondary Treatment (Anaerobic Phase)

There is another chamber called the anaerobic chamber with microorganisms inside. This treatment requires another chamber, because microorganisms are different in this process and the organisms require own chamber to update the nutrients anaerobically. The water with microorganisms is set to the chamber and microorganisms start activating and handling the process. (SSWM, 2014.)

3.3.3 Secondary Treatment (Secondary Clarifier)

The wastewater is five to six hours in aeration basin. After five or six hours the wastewater is directed to another clarifier which is called a secondary clarifier. This clarifier is called a secondary clarifier because it is bigger and placed in the secondary treatment. The clarifier's wastewater from the aeration tank or anaerobic tank starts reacting with the help of bacteria. In this reaction nutrients start to coagulate each other and sediments. Sediment nutrients form a layer at the bottom of the secondary clarifier as the sludge, and this sludge is called the secondary sludge. The secondary sludge continues to the sludge treatment process in convey pipes, see Figure 4. (SSWM, 2014.)

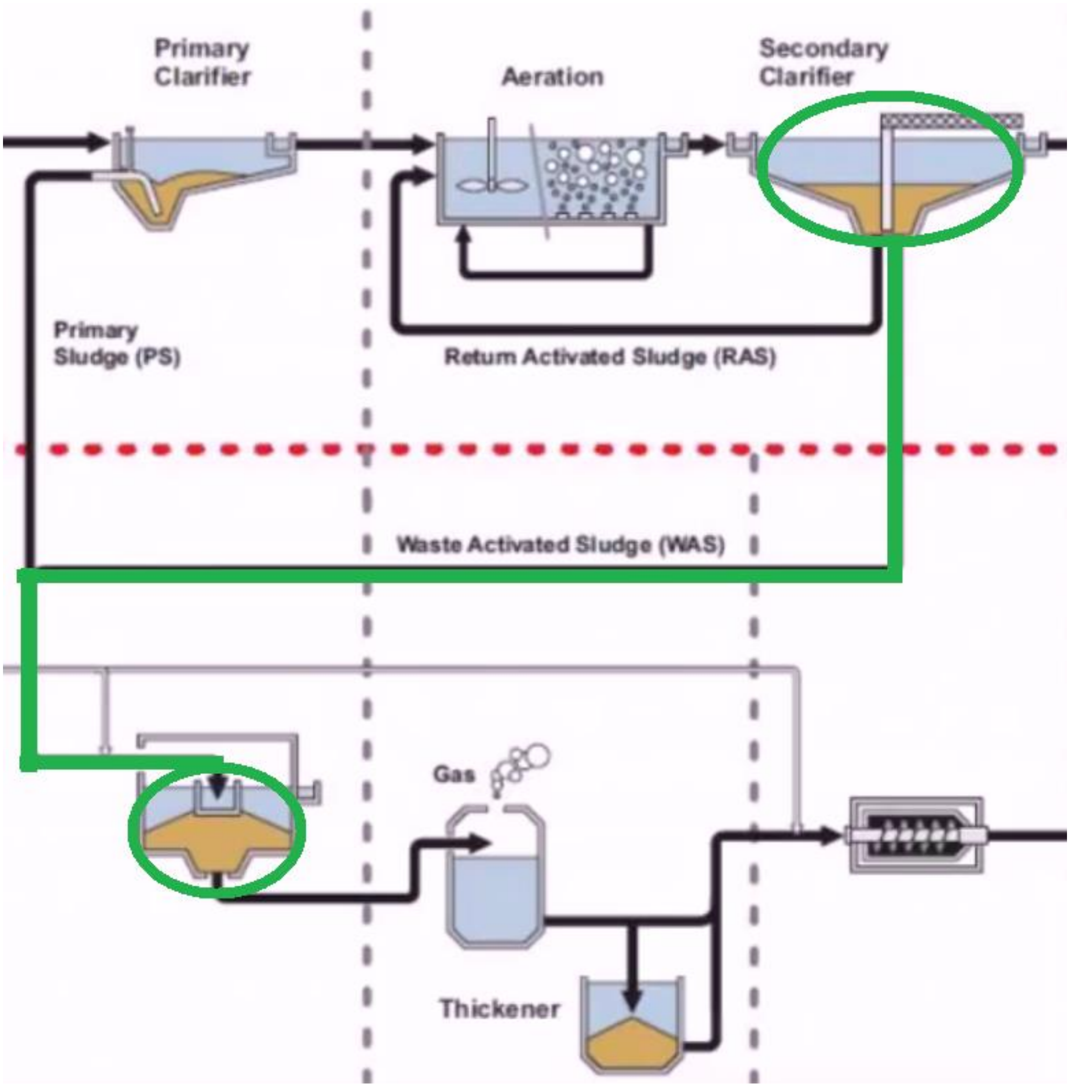


Figure 4. The secondary sludge, "waste activated sludge (WAS)" is directed to the sludge treatment process. (The original picture is shown in Appendix 6.)

3.4 Chemical Treatment

3.4.1 Tertiary Treatment

After the secondary treatment, water is directed to the third layer of wastewater treatment which is called tertiary treatment. This treatment method is also called chemical treatment because in this part chemicals get rid of bacteria in microorganisms (see Figure 5). Microorganisms have degraded their food material which is nutrient in water. That means microorganisms have done their job and they must be removed, because if they live in the water, they can be pathogenic for human. The chemical process will kill all those microorganisms in tertiary treatment by utilizing chlorination. Chlorination can be formal gaseous chlorine, formal liquid chlorine or tablet chlorine. (SSWM, 2014.)

The chlorine concentration must be controlled in this water. Sometimes a high amount of chlorine can be tasted in the water. This chlorine can cause damage to humans, because it's dangerous for any living. For example, humans, animals and planktons are harmed by a small amount of chlorine. If a high amount of chlorine is directed to streams, it can damage also fresh water flora. Therefore chlorine is removed until nutrients extinct. The UV disinfection is also a good method with chlorine disinfection. In order to assure cleaner water, it is considered to use both methods. After disinfection chlorine must be removed by using a SO_2 "sulfur dioxide" method. Sulfur dioxide is very important clearing method in the treatment. The method is called dechlorination and some alternative chemicals can be used for dechlorination such as Na "sodium", HSO_3 "bisulfite" or $NaHSO_3$ "sodium metabisulfite". (SSWM, 2014.)

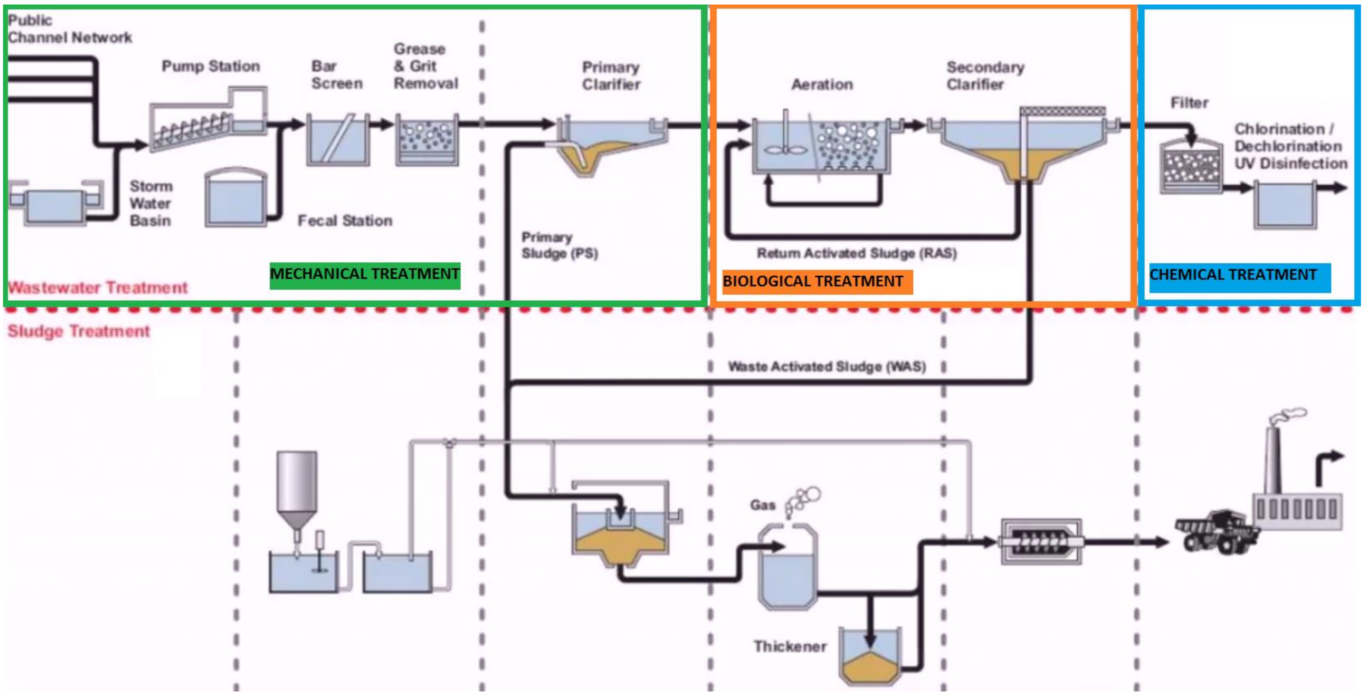


Figure 5. Mechanical, biological and chemical treatments. (The original picture is shown in Appendix 6.)

4 SLUDGE TREATMENT PROCESS

There is a huge amount of solid sediment material in the primary and secondary clarifiers. The solid material is sludge, which is stored at the bottom of the primary clarifier and the secondary clarifier. This material is directed to sludge treatment process from the primary clarifier as PS (Primary sludge) and from the secondary clarifier as secondary sludge or WAS (Waste activated sludge.)

4.1 Sludge Features

Primary sludge nutrients are dangerous to process. The sludge is toxic, but with a properly utilized process it might end up with a very economic product. Sludge contains some microorganisms and pathogens, emission of CH_4 gases, unpleasant odors and some heavy metals. The heavy metals in sludge make it a harmful by-product for wastewater treatment plants requiring a proper treatment and disposal. Primary sludge and waste activated sludge (secondary sludge) are utilized in the digestion chamber, where sludge produces methane gas, which is used as fuel in the treatment process. (M. Von, S. 2007.)

4.2 Treatment Process

There are three different process parts in the sludge treatment, sludge digestion, sludge thickening and sludge dewatering (see Figure 6). These three parts are the most important treatments in the sludge treatment process. Transportation is an alternative process, depending on wastewater and incineration plant's location. (M. Von, S. 2007.)

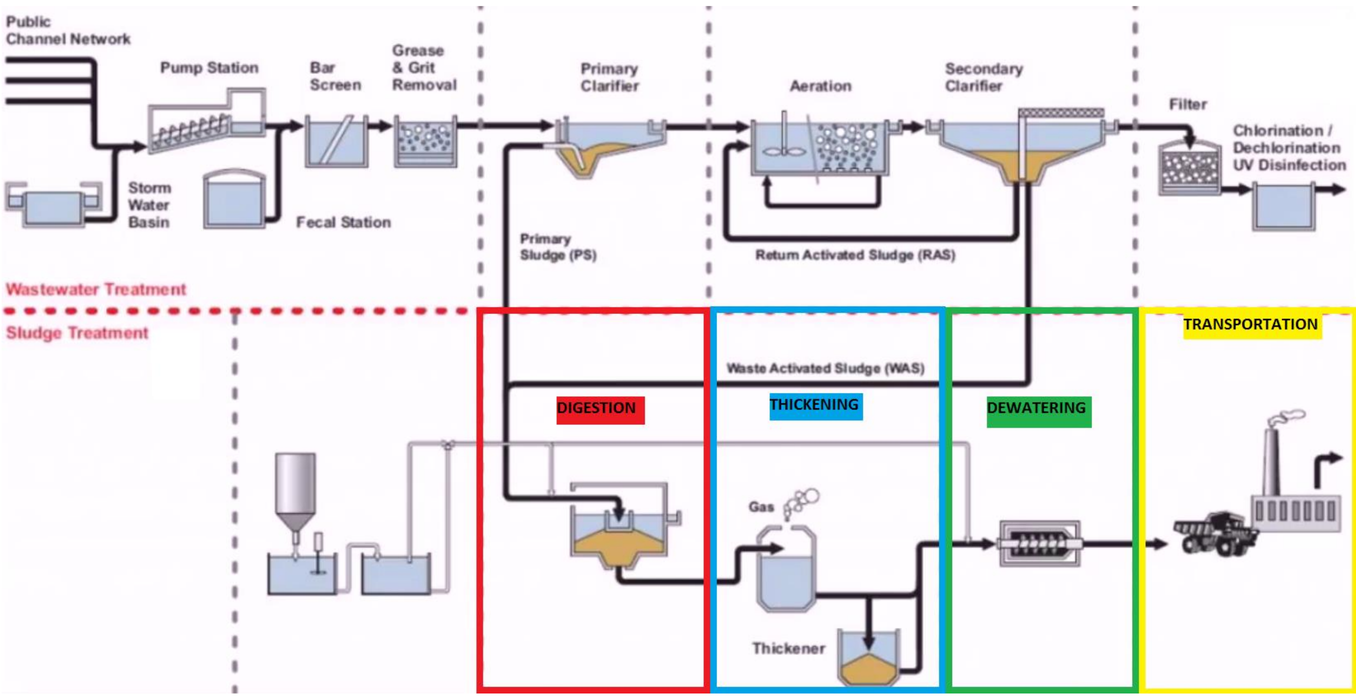


Figure 6. Four processes: Digestion, thickening, dewatering and alternative transportation. (The original picture is shown in Appendix 6.)

4.2.1 Sludge Digestion

The first treatment is sludge digestion. In this process sludge is transported by pipes and pumps to the digestion chamber. The purpose of digestion is to reduce the amount of organic matter and disease-causing microorganisms. Anaerobic digestion is still a long process, it lasts minimum twelve days to maximum thirty days in the chamber. In the digestion chamber heat is utilized among bacteria which are in the sludge to digest the sludge anaerobically. The anaerobic digested sludge produces methane gases. Microorganisms which are methanogens utilize carbon sources and generate these gases as the result of the process. The methane gas can be utilized as an energy source in sludge digestion. Stored methane gas runs fuel generators and fuel pumps in the wastewater plant sludge digestion. It is a circulation of the energy in the sludge digestion of a wastewater plant to utilize energy and heat from sludge digestion. (M. Von, S. 2007.)

Aerobic digestion is a process occurring in oxygen. Under oxygen bacteria rapidly consumes organic material converting it to carbon dioxide. Aerobic digestion occurs faster than anaerobic digestion but consumes more energy. Aerobic digestion requires blowers and pumps to add oxygen in this process. These days high technology enables to use natural air in this aerobic process and energy can be saved. It’s up to a user whether time is more precious than money while choosing digestion process between aerobic or anaerobic. (M. Von, S. 2007.)

4.2.2 Sludge Thickening

Sludge thickening is a process to reduce amount of water in sludge, making sludge thicker. There are common types of sludge thickeners, which are called DAFs (dissolved air flotation) or flow type of thickeners, shown in Figure 7. Those types of thickeners are inside huge chambers pushing air to sludge in very high pressure. Pressure is released to sludge and sludge will flow out of the chamber while floating on water. The result is solid and thick sludge leaving watering parts in the bottom. Usually sludge thickening occurs before sludge digestion, but in Figure 6 it is after digestion treatment. (M. Von, S. 2007.)

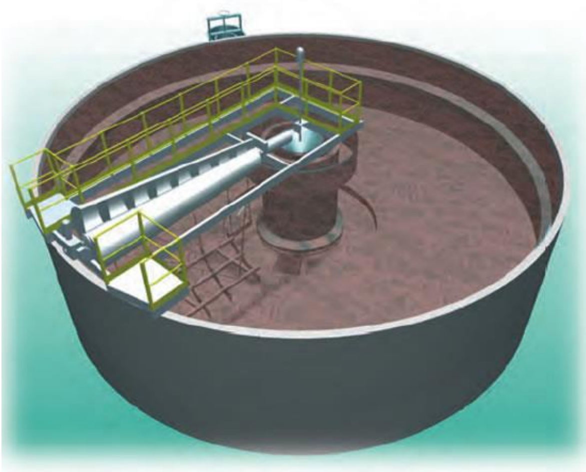


Figure 7. Sludge thickening pool. (ENVIROPRO, 2015.)

4.2.3 Mechanical methods of Sludge Dewatering and Thickening

Sludge dewatering and thickening in other words sludge drying or separation are particular states to remove any wet materials from sludge. The methods to remove water from sludge such are centrifuges, filter presses, belt filters, rotatory drums and gravity filter thickening. Sludge dewatering reduces the volume of sludge which is transported to next treatment which could be possibly incineration.

4.3 Polymers

Polymers are large organic molecules, which coagulate with suspended solids to produce large curds of solid materials. Polymers in drying improve the process and are used for example, in centrifuges. There is a specific polymer feeding system to improve sludge dryness. "Sludge treatment and disposal of sludge can be very costly. It is therefore important that sludge volumes are kept at a minimum with a high dry-solids content to reduce disposal costs." (Kemira, 2015.) Polymers are used in dewatering process and will improve water releasing from sludge. It will help to produce drier material and decrease volume of sludge.

4.4 Overview Comparison

This comparison in Table 1 is for different sludge dewatering and thickening methods. Centrifuges or belt filter presses with gravity belt thickening are used as basic sludge dewatering and thickening systems. One major reason those systems are chosen is because the process time and drying time is shorter than in any other method.

Table 1. IHS 360 price compare to different separation methods. (IHS Engineering 360, 2015.)

Type	Cake Dryness	Solids Recovery	Process / Drying Time	Operating Cost	Capital Cost	Chemical / Flocculent
	% solids	% solids capture	time (measurement)			Usage
Vacuum filters	16 – 45*	85 - 95	Fast (minutes or hours)	High	Moderate	Moderate
Filter presses	40 – 60	80 - 95	Very fast (minutes)	High	High	High
Centrifuges	20 – 35**	85 - 90	Fast (minutes or hours)	Moderate	Low	High
Drying beds	25 – 60	90 - 100	Slow (weeks or months)	Very low	Low	Low
Sludge lagoons	20 – 40	90 - 100	Very slow (months or years)	None	Very low	None
Gravity/Low Pressure	10 – 50	90 - 96	Moderate (days or weeks)	Low	Moderate	High

4.4.1 Centrifuge

In Figure 8 it can be seen a common dewatering system which is a centrifuge's helical scroll. The centrifuge used in wastewater and in sludge treatment is called a solid bowl centrifuge, where the helical scroll pushes sludge in a rotating bowl. Liquid is discharged from the bottom of the bowl and solids are discharged at tip of the bowl. Centrifuges are simple solutions for sludge processing.

Figure 8. The helical scroll which pushes the sludge,
ANDRITZ Centrifuge manufacturing in China. (Photo taken in Foshan, Guangdong.)

Advantages:

- Requires minimum space
- Easy maintenance
- Lower power consumption
- Simple and easy solution

Disadvantages:

- Generates heat
- Vibration may occur in some operation points
- May cause noise

4.4.2 Skeleton Model Filter press

In the Figure 9 there is a filter press, which is one of the separation methods, that separates solids and liquid. The slurry pump pushes sludge inside filter packs and the skeleton model holds those filter packs together. The filter press slurry pump gives high pressure inside packs and liquid is filtered out. After that the packs open and the sludge is collected as cakes to further process. The sludge, which is kept inside the cake packs, holds only a specific volume of solids.

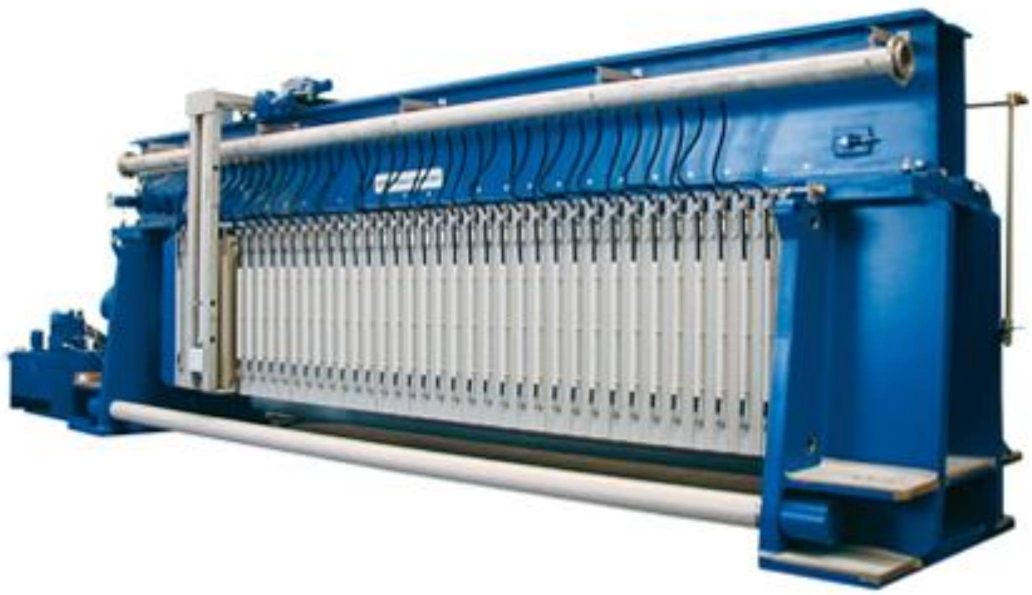


Figure 9. Skeleton model filter press by ANDRITZ. (ANDRITZ Filter Press, 2015.)

Advantages:

- Can be fully automatic
- High liquid and solids separation

Disadvantages:

- Slow compared to other separation methods
- Requires washing
- Requires more space than other dewatering systems

4.4.3 Belt Filter Press

A belt filter press has two belts and many rollers which give high pressure and keep belts tight. The compressed material, in this case sludge, moves between two belts until a scraper knife removes dry material from the belt like in Figure 10. Liquid is discharged at the bottom of the machine and doesn't stay in the belt's surface. Filter presses are designed to remove liquid before transportation, landfill disposal, further drying or incineration.

Figure 10. Belt filter press where sludge is scraped off by scraper "knife" (ANDRITZ PDF 带式浓缩/脱水一体机. 2015.)

Advantages:

- Easy maintenance and open inspection
- Quick startup and less noise
- Long life
- Low energy cost

Disadvantages:

- Odor of feed sludge
- Sharp objects can damage the belt
- Requires washing
- High content of grease or oil is a problem

4.4.4 Gravity Belt Thickener

The gravity belt is placed before the belt thickener and conditions the sludge by passing through filter area making the sludge slurry. The sludge material is scraped by the filter screen scrapers and it creates sludge trails for water to drain freely. The gravity belt doesn't share the belt with the belt filter press. Figure 11 shows the gravity belt thickener's trails.

Figure 11. Gravity belt thickener (ANDRITZ PDF 带式浓缩/脱水一体机. 2015.)

Advantages:

- Can be combined with the belt filter press
- Easy to do maintenance
- Low energy consumption
- Quick startup and lesser noise

Disadvantages:

- Requires a lot of space
- Sharp objects can damage the belt
- Odor of feed sludge

4.4.5 Rotatory Drum

The rotatory drum's separation technique suits well to separate slurries and liquids. The rotatory drum working principle is spinning and vacuuming force inside the central duct to separate liquid with high solid content. The suction force keeps solids on the dewatering cylinder zone while cylinder is spinning. The spinning sludge won't be removed until the scraper knife cuts the material from the cylinder's surface (see Rotatory drum in Figure 12.)

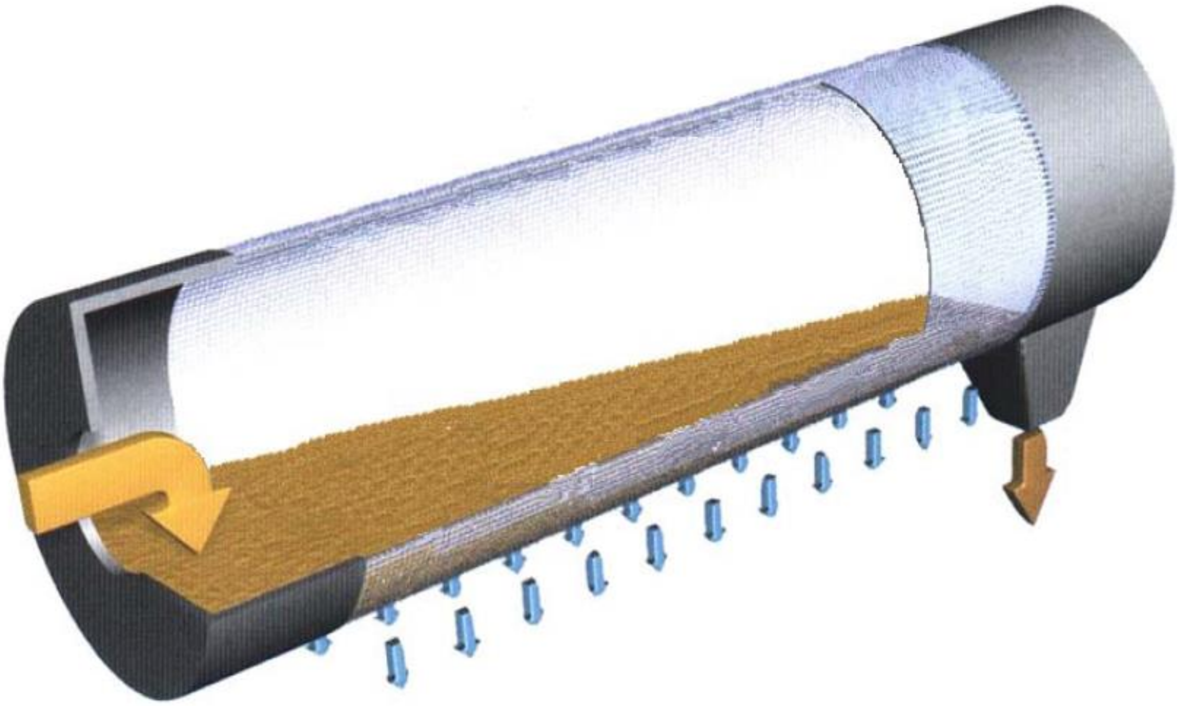


Figure 12. Rotatory drum. (ANDRITZ PDF 带式浓缩/脱水一体机. 2015.)

Advantages:

- A continuous process and low cost
- A cleaner process when added a showering device

Disadvantages:

- Vacuum pumps and agitators are required
- High energy consumption in vacuum pumps
- Discharged sludge may contain residual moisture

5 TYPICAL SLUDGE VOLUME

The typical and approximate sludge MC (moisture content) of 99.5% contains 5 kg dry SS (solid sludge). The volume V2 is produced by drying, dewatering or thickening a volume of sludge V1, from MC1 to MC2, where Volume 2 can be calculated as follows:

$$V2 = V1 \times \frac{100-MC1}{100-MC2} = V1 \times \frac{SC1}{SC2} \qquad (1)$$

where V1 is sludge volume before dewatering, ie. chosen $1m^3$

V2 is sludge volume after dewatering

MC1 is moisture content before dewatering

MC2 is moisture content after dewatering

SC1 is solid content before dewatering

SC2 is solid content after dewatering

If the sludge moisture content before drying is 99.5%, the calculated volume after drying to MC 99% is 0.500 m^3. The volume affection can be seen in Table 2, where the previous state of volume changes to current state of sludge volume indicating the change by affection percentage.

Table 2. Sludge moisture content and volume content with volume affection.

Moisture %	Volume [m^3]	Fixed Volume [m^3]	Volume affection
99,5	1,0000	0,9986	No affection
99	0,5000	0,4986	50 %
98	0,2500	0,2486	50 %
97	0,1667	0,1652	34 %
96	0,1250	0,1236	25 %
95	0,1000	0,0986	20 %
94	0,0833	0,0819	17 %
93	0,0714	0,0700	15 %
92	0,0625	0,0611	13 %
91	0,0556	0,0541	11 %
90	0,0500	0,0486	10 %
89	0,0455	0,0440	9 %
88	0,0417	0,0402	9 %
87	0,0385	0,0370	8 %
86	0,0357	0,0343	7 %
85	0,0333	0,0319	7 %

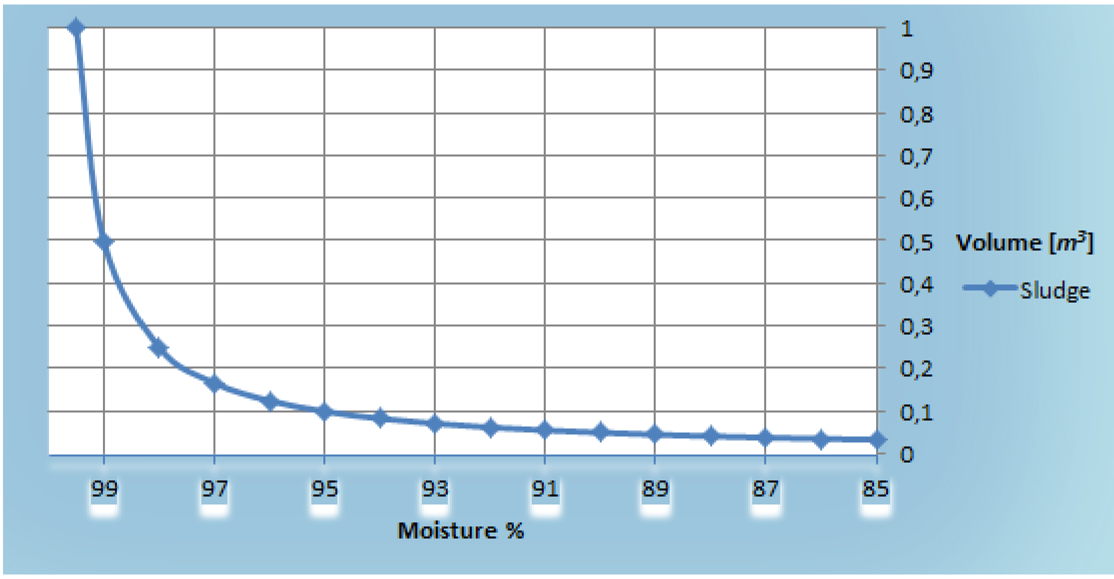


Chart 1. Sludge volume as a function of moisture content.

Chart 1 indicates the huge sludge volume reduction, when dewatered from MC 95.5% to 85%. The sludge volume requires fixed volume calculation to indicate the more accurate sludge volume. The fixed volume is calculated as follows:

$$Vf = \frac{SS}{DS\rho} + \frac{(V2 \times 1000 - SS)}{W\rho} \qquad (2)$$

where	Wρ	= Water density [1000 kg/m^3]
	DSρ	= Dry sludge density [1400 kg/m^3]
	SS	= Solid sludge content [5 kg/m^3]

If the sludge moisture content is 99.5%, the calculated fixed volume Vf is 0,9986 m^3 and if the sludge moisture content is 99%, the fixed volume Vf is 0,4986 m^3.

The volume of the sludge is decreased by huge amount at certain point. Dewatering sludge from 99.5% to 95% reduces approximately 90% of the volume making it easier to transport. In Table 3 the sludge moisture content and volumes are shown by 10% moisture change. The affection is compared by reducing current moisture content by 10%.

Table 3. Sludge dewatering 10%

Moisture %	Volume [m^3]	Fixed Volume [m^3]	Volume affection
80	0,0250	0,0236	51 %
70	0,0167	0,0152	35 %
60	0,0125	0,0111	27 %
50	0,0100	0,0086	23 %
40	0,0083	0,0069	19 %
30	0,0071	0,0057	17 %
20	0,0063	0,0048	16 %
10	0,0056	0,0041	14 %

6 SLUDGE TREATMENT ALTERNATIVES

Sludge utilization and competition depends on environmental outcome. It is always favorable to use the most effective and environmental friendly way to dispose sludge. The benefits from most high-technology solutions are listed in the sludge pyramid in Figure 13.

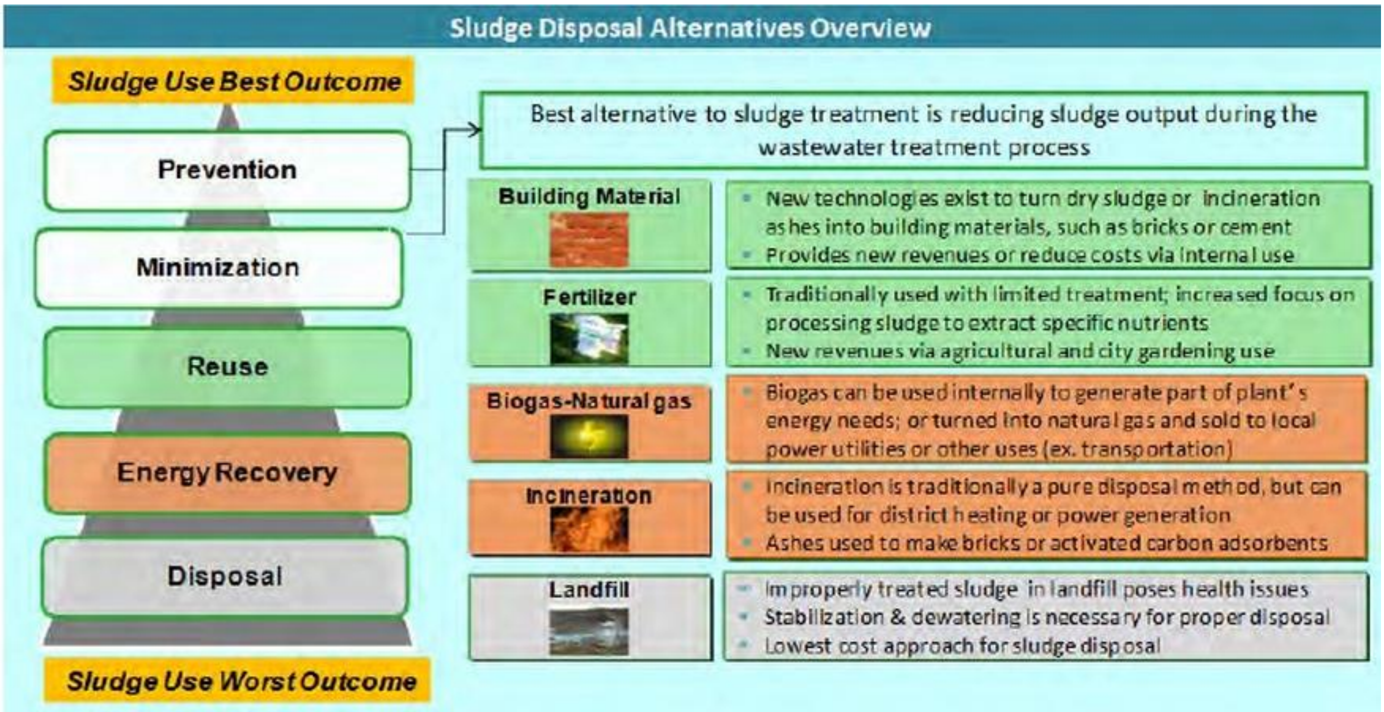


Figure 13. Sludge disposal alternatives. (China Greentech, 2011.)

Table 4 represents sewage sludge treatment and disposal costs by RMB/ton sludge. The table is sorted from the lowest cost to the highest cost where landfill is the most popular and is a cheap method compared to incineration. Incineration as sludge disposal should raise huge interests due to volume reducing and not causing landfill problems. (B. Raninger, R. Li, 2012.)

Sludge Treatment and Disposal Solution Cost Overview

Treatment or Disposal Method	Cost (RMB/ton sludge)	Cost (RMB/ton sewage)	Current Situation
Discard into Environ.	15	0.01	▪ Often used in the industry
Landfill	40~56	0.03~0.03	▪ Often used in the industry
Anaerobic digestion	50~150	0.03~0.09	▪ Quickly becoming an option
Simple compost	70~100	0.04~0.06	▪ Often used in the industry
Mechanized compost	120~200	0.07~0.12	▪ At experimental stage
Heat drying	160~360	0.10~0.22	▪ More used in large projects due to high cost
Incineration	220~500	0.13~0.30	▪ More used in large projects due to high cost

6.1 Sludge Reuse as Building Material

China is growing rapidly and the demands of cement in industrial use have increased. The way to reduce environmental damage of cement production is called "green cement". This method is the Chinese government's one of the top research priorities. The most increasing need of cement industries are growing in China. The estimated worldwide growth from the current situation is doubled amount of cement by the beginning of 2030 year.

Sludge benefits as using it as a resource to produce cement, ceramic cubes or bricks vary on its dryness. The sludge must be dried and the initial investment depends on the cost of dewatering and drying equipment. In China, green cement projects, for example in Beijing Cement's sludge to cement project, have become an economic failure. High investment costs are typically the reason. Whether there is a low investment cost, the sludge as building material won't overcome its quality barrier. This requires further development in quality until sludge cement benefits can be utilized. (China Greentech, 2011.)

6.2 Sludge as Natural Gas

This method is usually used in treatment plants, whether there is a greater need of energy in treatment plant or the consumers need more energy. Whether all of the China's 30 million tons of sludge were treated anaerobically, it would produce 2.5 billion cubic meters methane gas. That amount of methane gas could generate 4 billion kWh of electricity (4,000GWh; 4TWh) and reduce carbon emissions annually by 15 million tons. On the other hand, processing huge amount of sludge requires large degradation chambers (see Figure 14). The degradation chamber, where the process takes long time and is difficult to implement, processing heat for power use depends on organic levels in sludge. Low organic level affects biogas quality, volume and may cause methane releases. (China Greentech, 2011.)

Figure 14. Anaerobic digestion in Hangzhou, where sludge is producing biogas. (Asian Development Bank, 2012.)

6.3 Sludge as Landfill

Sludge is regulated to be hazardous waste. Untreated sludge pollutes groundwater, infiltrates soil and releases methane gases into atmosphere. Therefore sludge disposing as landfill is the least attractive method. Sludge disposal as landfill is a popular, easy and low cost method even though it has health and environmental impact in China. To fulfill regulations and the government's approval, the sludge water content must be below 60% in order to dispose sludge safely. (China Greentech, 2011.)

6.4 Sludge Incineration

Sludge as incineration treatment can produce electricity and heating. Incineration doesn't require so large space compared to landfilling. Therefore China uses sludge incineration as quick solution instead of landfill disposal, which causes huge amount of soil emissions. On the other hand incineration requires sludge to be dried and the energy efficiency is low due to its low calorific content. Some sludge incineration plants use coal or oil as auxiliary fuel to increase heating output. This incineration produces residues such like flue gas, which raises air pollution problems. Ash residues can be utilized to activated-carbon absorbents or bricks. (China Greentech, 2011.)

6.5 Sludge as Fertilizer

Sludge use as fertilizers means it is utilized for garden or agricultural use. Sludge in fertilizing utilizes sludge's own nutrients such as nitrogen and phosphorous. It is a very economic method to reuse nutrients. There isn't any right method to completely process sludge, but the use of fertilizer is coming even more popular since it is cheap treatment compared to incineration. In addition this sludge must still be treated properly or there is a risk of soil pollution. Toxins and other pollutants must be removed to prevent any emission issues. However, industrial sludge cannot be used as fertilizer due to its high heavy metal content. (China Greentech, 2011.)

7 INCINERATION AND WASTE MANAGEMENT

IWM (Integrated Waste Management) idea is to safely handle municipal solid waste. One part of this is to handle municipal solid sludge. The most favorable method for waste disposal is reduction and the least desirable is landfilling (see Figure 15). Separating any renewable materials or anaerobic digestion are more important than incineration, even though incineration can reduce waste volume up to 90% and weight 75%, and also eliminate hazardous substances such as toxic chemicals and pathogens. The industrial waste and sludge contains more toxic substances compared to municipal sludge and cannot be recycled. Therefor it is desirable to incinerate any kind of industrial waste. Whether the waste contains huge amount of mixed organic material or wet food waste, it should be examined for anaerobic digestion possibilities.

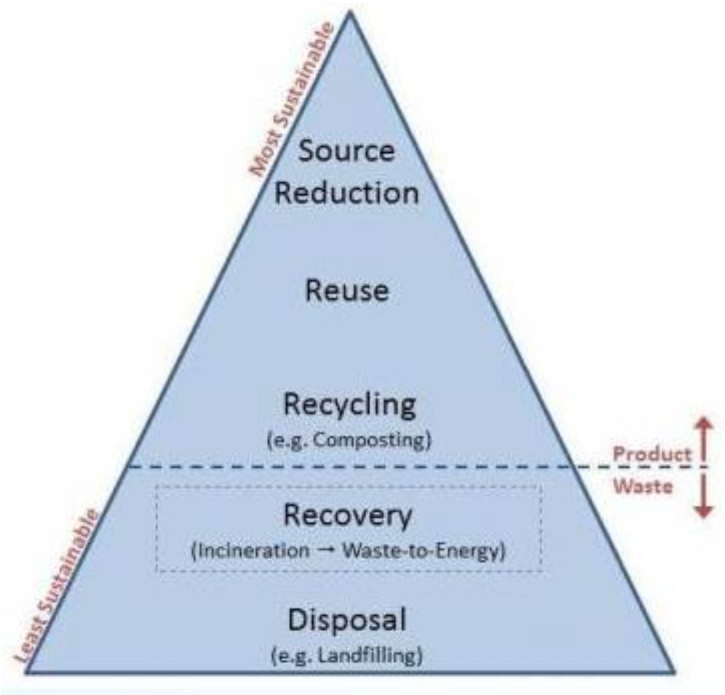


Figure 15. Pyramid for waste treatment; Source reduction, disposal, recycling, recovery and reuse. (Beat, S., Dorothee, S. 2012.)

7.1 Incineration

Sludge incineration technology in Europe cannot be copied to China because municipal sludge in China contains more wet materials compared to European sludge. The wet materials are often huge amount of kitchen wastes. Municipal waste, for example, mixture of toilet waste requires much more energy to incinerate, which causes the requirement of sludge, which must be dryer than in Europe.

There are three types of huge scale incineration techniques: fluidized bed incineration, modular incineration and mass-burn incineration. Sludge incineration can be incinerated with other waste materials such as household wastes. The incineration destroys all sludge contaminant features so it doesn't cause soil emission problems in treatment. The other major reason for sludge incineration is the huge amount of sludge produced in WWPs and scarcity of landfill to dump the sludge. That is why sludge incineration has come more popular in China.

Many existing plants use coal or oil as auxiliary fuel to produce heat and power to grid in China. In Figure 16 sludge is integrated with waste as combined incineration. There is an example of a combined waste incineration plant, which is Likeng incinerator plant. The Likeng plant in Guangzhou burns 1000 tons a day municipal waste and coal. The waste contains 70% of water. The huge water content can be explained by the huge amount of food materials or household garbage. The facility generates 320 – 350 MW power and 80% of that is exported. The incineration design and operation comes from Veolia and Veolia claims to be the leading water supply, wastewater, waste management, energy and transport company in China. The Likeng incinerator has made dramatic public concerns in environmental sector (IPEN and Green Beagle, 2015.) Burning coal and waste have caused air pollution problems; water is not drinkable for local people causing health problems and many people consider leaving the area. There were two emission data tests about dioxin, but both failed EU2000 limits. The estimations on huge polluting occur because "techniques and obligations to implement a relevant international treaty are ignored", and "China needs a functioning polluter pays system so that polluting facilities are not simply externalizing their costs onto the population", (IPEN and Green Beagle, 2015.) Incineration is huge question whether it's chosen to be the sludge and waste disposal method, because of emission control.

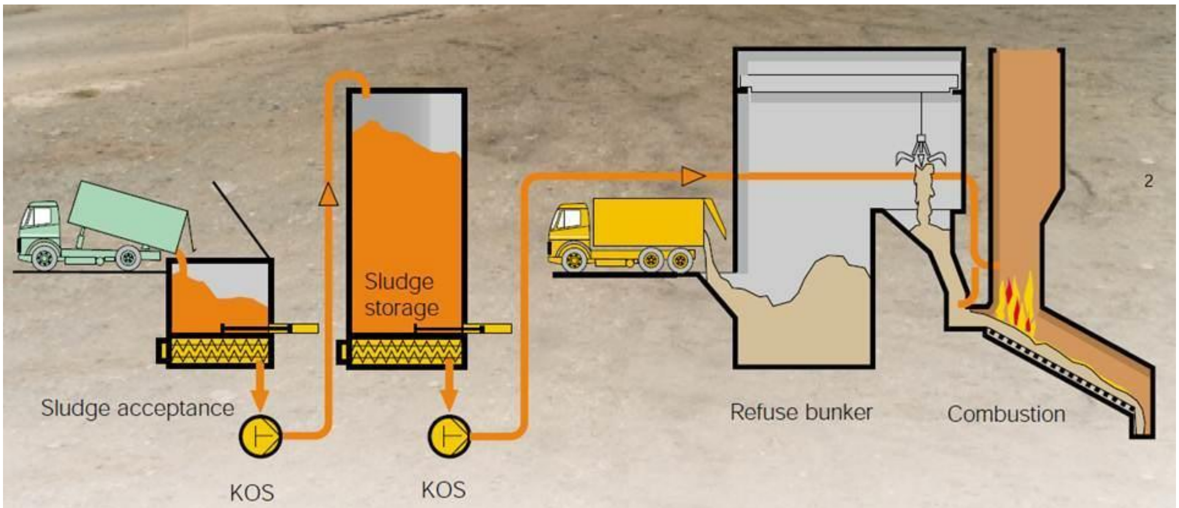


Figure 16. In this picture sludge acceptance and the sludge is directed to storage, then transported to combustion chamber. The sludge can be integrated with household rubbish and incinerated. (Beat, S., Dorothee, S. 2012.)

7.1.1 Mass-burn Incineration

Mass burn incineration can accept little processed waste, although this method is convenient and flexible. The method separates household hazardous wastes and recovers certain materials such as iron scraps in order to ensure environmental protection. Its incineration capacity ranges from 50 to 1000 tons per day by each incineration units. Mass burn incinerators usually have two or three incineration units, where incineration is over 1500˚C degrees and the total facility capacity ranges from 100 to 3000 tons per day. Usually the mass burn incineration technique is good at reducing volume, but there are issues for any kind of incineration. The location must be suitable and usually it's placed near industrial areas, because people don't want to live near incineration plants. Incineration facilities are usually expensive to build, ranging from 100 – 300 USD per ton of waste disposal. In addition, mass burn incinerators cause huge concern for emission and producing ash and hazardous substances, which require specific landfill area for disposal.

The mass burn incineration process is shown in Figure 17. "Waste is tipped into a holding area (1) where it is picked up by grabs and dropped into a hopper (2). The waste is pushed gradually into the incinerator (3) which runs at a temperature of 750 °C. Heat from the burning waste is used in a boiler (4) and steam from this is piped to a turbine generator to create electricity. The heaviest ash falls into a collection point (5) and is passed over with an electromagnet to extract metal content for recycling. Flue gases containing fine ash then pass through a scrubber reactor (6) to treat acid pollutants such as SO_2 and also dioxins. The gases then pass through a fine particulate removal system (7) and are released through the chimney stack (8)". (Beat, S., Dorothee, S. 2012.)

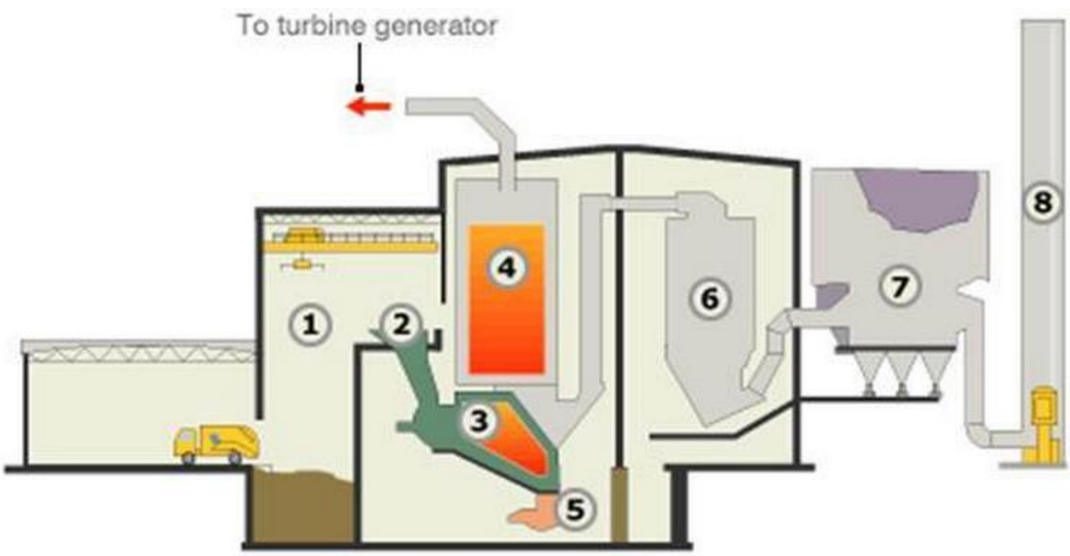


Figure 17. Mass burn incineration and processing waste materials. (Beat, S., Dorothee, S. 2012.)

7.1.2 Fluidized-bed Incineration

In fluidized bed incineration air distribution system's combustion air passes sand or limestone layer, which can keep high temperature inside. The fuel is mixed to bed material, which will cause the combustion in furnace. Air velocity and bed material start behaving like fluid and the fluid starts bubbling. The term fluidized comes from bed heating and increasing air velocity, which causes the bed to bubble (see Figure 18). There are two suitable municipal solid waste incineration techniques for fluidized bed incineration: A bubbling bed and a circulating bed boiler. The differences vary between bed material and air flow with impact of the wastes that can be burned. Some fluidized beds include an energy recovery system and a heat transfer. (Beat, S., Dorothee, S. 2012.)

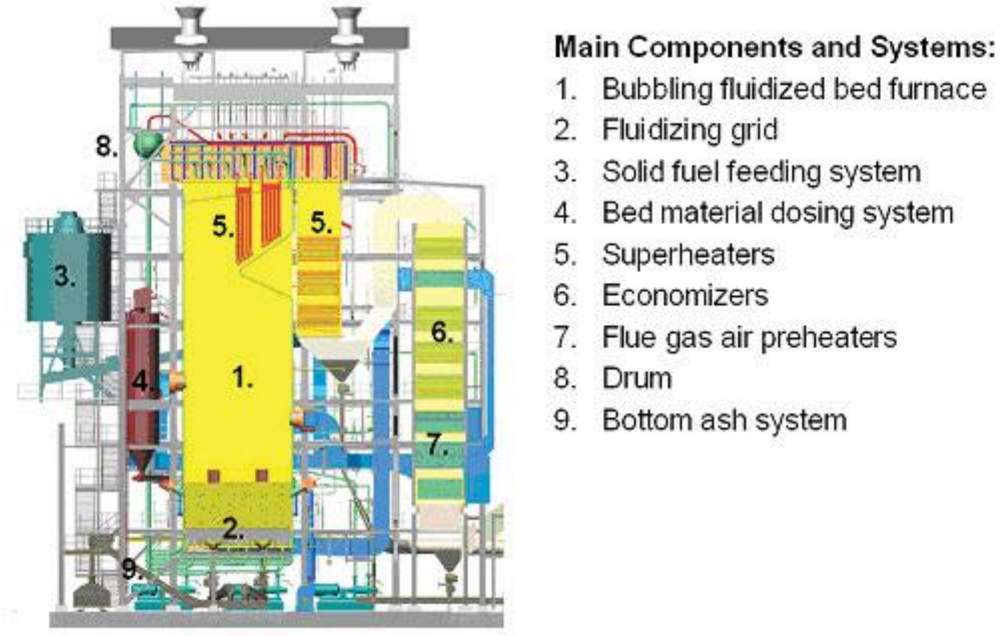


Figure 18. ANDRITZ BFB (Bubbling Fluidized Bed). (TAPPSA, 2009.)

A BFB and CFB can burn more than coal as fuel in incineration (see figure 19). The fuel benefits vary on incineration temperature, which is usually between 750˚C - 900˚C. The lower temperature compared to other incineration technologies has such benefits as lower NO_X and SO_X production, lower air pollution, less area requirements, better combustion efficiency and heat transfer.

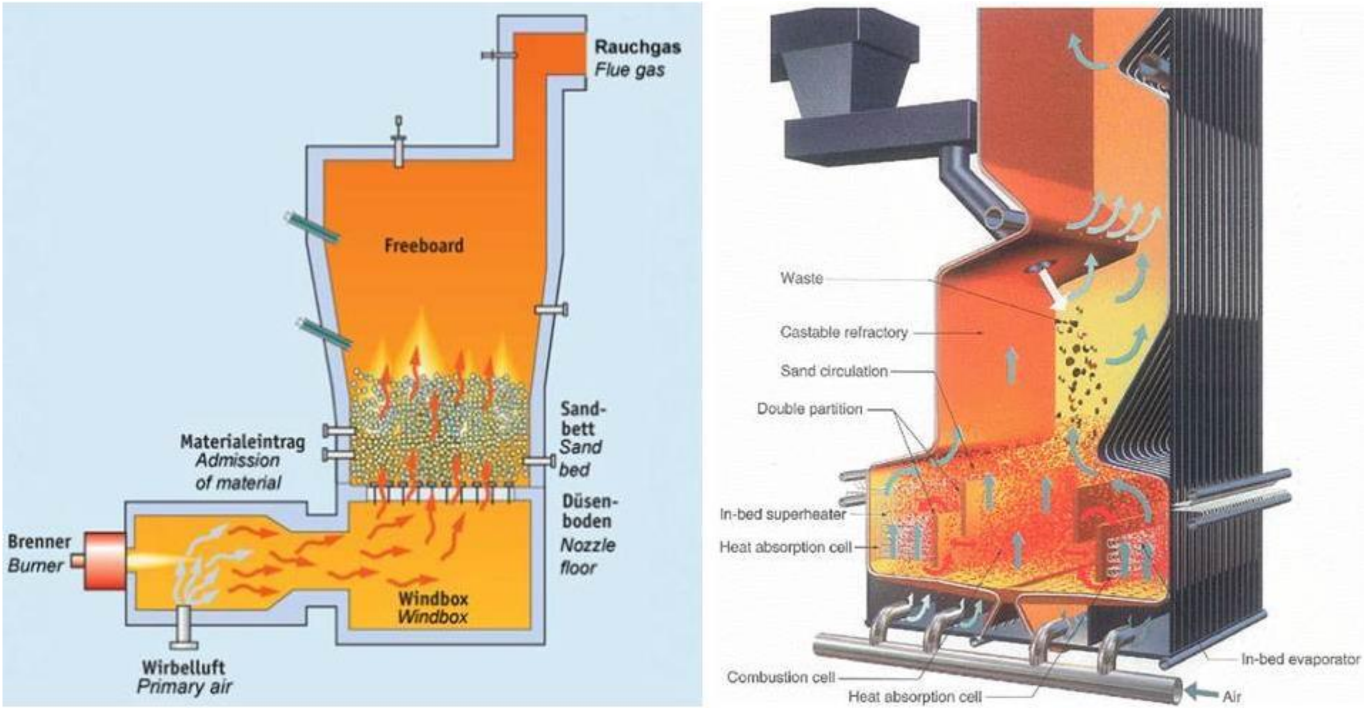


Figure 19. Combustion process. Bubbling bed on the left side and circulating bed on right side. (Beat, S., Dorothee, S. 2012.)

7.1.2.1 Mono-Combustion and Co-Combustion

Generally co-combustion can accept any burnable material in co-incineration. Commonly, coal or oil is used as auxiliary fuel in co-combustion. Sometimes wood or agricultural waste is added in the combustion process. The amount of auxiliary fuel depends on sludge's quality. Important features are moisture content and sludge content, e.g. what material sludge includes.

Mono-combustion is usually a simple designed structure. It's meant to destroy sludge without utilizing energy recovery, because the heat value doesn't reach required calorific values. Whether sludge is digested its calorific heat value is getting even lower and it doesn't suit for heat recovery. The typical calorific heat value for sludge DS is about 3 MJ/kg. Heat values are listed in the Appendix 5. In the Shidongkou incineration plant dewatered and dried sludge has 11.6 MJ/kg, where sludge isn't digested. Commonly sludge heat value depends on sludge material content and organic matters in sludge. (Beat, S., Dorothee, S. 2012.)

The minimum acceptable heat content requirement for hazardous waste is from 5,000 Btu/lb (= 11.629 MJ/kg) to 4,000 Btu/lb (=9.304 MJ/kg) for wastes with "significant organic content. (Michael, S. 1994). The minimum acceptable heat value creates a conclusion in Shidongkou incineration plant, which burns sludge with minimum heat value requirement, which is between 11.6 - 9.30 MJ/kg. Lower heat values require auxiliary fuel to maintain heat production in incineration.

7.1.3 Modular Incineration

Modular incinerators, also known as moving grates, are usually used in industrial operation. The design gives shorter construction time which is its advantage. One incinerator can burn approximately 5 to 120 tons of solid waste and typical modular incineration facilities have one to four incineration units. Typically modular incinerators have two chambers for combustion. The first chamber incinerates solid wastes and the second incinerates gases which are generated in the first chamber. Gases flow to the second chamber afterburner from the first chamber as can be seen in Figure 20. (Beat, S., Dorothee, S. 2012.)

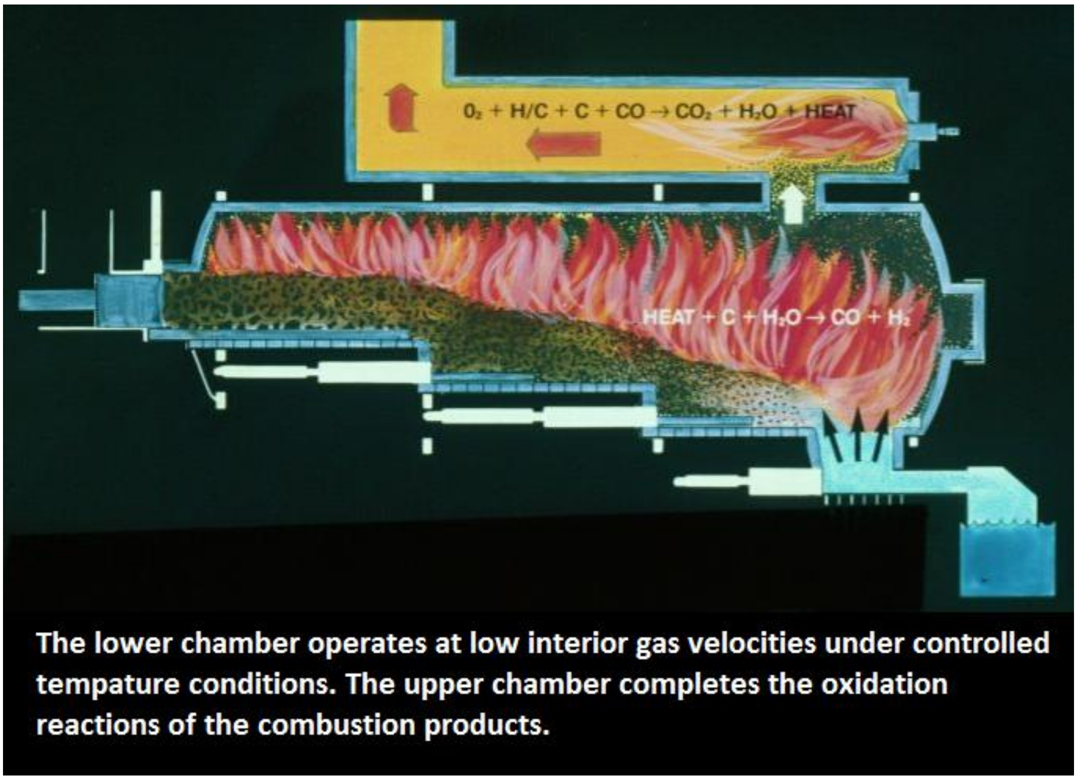


Figure 20. Modular combustion chamber. (Beat, S., Dorothee, S. 2012.)

8 SUPPORTERS AND EVENTS

Sludge dumping as landfill has infected underground water resources in China. Many organizations are against this sludge treatment method and possible protectors are Ministry of Water Resources the People's Republic of China. The Chinese government is one of the most important supporters and most projects are started by the government's support or investment in public energy and environmental sector.

A list of governmental authorities that increase sludge business possibilities in China:

- MOHURD - Ministry of Housing and Urban-Rural Development
- NDRC - National Development and Reform Commission
- MOEP/MEP - Ministry of Environmental Protection

8.1 13th Five Year Plan

13th FYP will take place between years 2016 – 2020. It is unknown which key factors are chosen as sludge disposal future views. The key factors are financing, fees or tariffs, quality and standards with supervision and monitoring, plants to execute at city level as integrated solution, choosing appropriate techniques or selecting solutions, increasing public awareness and knowledge.

The next FYP will be implemented as following:

- STEP 1: December 24, 2014 Review of 12th FYP
- STEP 2: January 15, 2015 NDRC selects the main research areas
- STEP 3: February 15, 2015 NDRC creates general guidelines, work schedule
- STEP 4: October 15, 2015 Consultative draft will be developed
- STEP 5: October 18, 2015 Communist Party of China CPC meeting on the 5th plenary session
- STEP 6: January 15, 2016 National experts discuss about 13th FYP draft
- STEP 7: February 15, 2016 The 13th FYP draft will be finished
- STEP 8: February 15, 2016 Premier Li Keqiang collects opinions from social media
- STEP 9: March 14, 2016 The 13th FYP will be submitted and accepted
- STEP 10: March 15, 2016 The 13th FYP will be implemented in China
  (Environmental Performance Index, 2015.)

After the last step, sludge disposal future views and regulations will be announced for public use and can be utilized in sludge business markets.

9 BUSINESS

Many foreign companies are in a good situation taking advantage of China's air pollution and wastewater opportunities. "As for European countries, they have the advanced technology and high safety standards needed in a green economy. They also have environmental protection technology. During China's transition, it will need to import materials and technology from Europe. So that transition won't have a big impact on Europe, there'll just be a change in where the growth comes from." (Zhang, C., Xu, N. 2014.) The market opportunities should represent huge potential by given estimation the 22 to 30 million tons of sludge is discharged annually from WWP's. 80% of the sludge is untreated and the raw sludge from wastewater plants is usually 97% - 99.5% MC (see Table 5).

9.1 Calculations on Business Opportunities in Boiler Sales

Whether 22 000 000 to 30 000 000 tons of sludge is produced each year in China, it represents approximately 26 000 000 tons of sludge produced a year. 80% of the sludge is untreated sludge and the average MC of untreated sludge from WWP is 98.25%. The rest 20% is treated sludge (for example dewatered or thickened sludge) and MC estimation is 60%, which is ready to be burned without any treatment.

Table 5. The moisture and volume contents of sludge, where raw sludge MC from WWP's is between 97% and 99.5%.

Moisture %	Volume [m^3]	Fixed Volume [m^3]	Volume affection
99,5	1,0000	0,9986	No affection
99,25	0,6667	0,6652	33 %
99	0,5000	0,4986	25 %
98,75	0,4000	0,3986	20 %
98,5	0,3333	0,3319	17 %
98,25	0,2857	0,2843	14 %
98	0,2500	0,2486	13 %
97,75	0,2222	0,2208	11 %
97,5	0,2000	0,1986	10 %
97,25	0,1818	0,1804	9 %
97	0,1667	0,1652	8 %

Huge scale incineration plants can process 200 tons of sludge each day and a small scale incineration plant would burn approximately 100 tons sludge each day. The estimation is created on sludge incineration, where sludge incineration will be increased by 3.5% each year. The sludge burned an in incineration plant would be 60% MC. The Appendix 2, 3 and 4 describe how ANDRITZ offers different sludge incineration solutions with 65% MC. The 5% MC between designed and calculated MC value is noticed as a safety marginal in this case.

UNTREATED SLUDGE

The total amount of China's sludge is 26 000 000 tons produced annually, where 80% is untreated sludge and the approximate MC of that sludge is 98.25% with volume of 0,3319m³. The sludge with MC of 98.25% must be dewatered to sludge with MC of 60%, whether the sludge is incinerated. From that untreated sludge the potential amount of small scale incineration plants needed with 3.5% increased incineration for one year is calculated as follows:

$$X1 = \frac{Vs \times Vr \times Tr}{365d} \times Ii \div Y \qquad (3)$$

where	X1	is amount of incineration plants needed with untreated sludge
	Vs	is sludge volume $[\mathrm{m}^3]$
	Vr	is sludge volume rate change from V1 to V2
	Tr	is sludge treatment rate of total amount of sludge [%]
	Ii	is increased incineration potential [%]
	Y	is amount of sludge a single plant can treat a day [tons/d]

when	Tr	= 80%
	Vr	$= \frac{\mathrm{V(60\%\ MC)}}{\mathrm{V(98.25\%\ MC)}} = \frac{0{,}0111\mathrm{m}^3}{0{,}2843\mathrm{m}^3} = 0{,}039$
	Y	$= 100\ \frac{\mathrm{tons}}{\mathrm{day}}$ treatment

With untreated sludge and values of Tr, Vr and Y given above, the amount of incineration plants needed is calculated in Formula 3, which gives the estimation 0,78 (rounded up to 1) incineration plant needed annually.

TREATED SLUDGE

The total amount of produced sludge in China is 26 000 000 tons annually, where 20% is treated sludge and the approximate MC of that sludge is 60% with volume of 0,0111m³. This sludge with MC of 60% doesn't require any dewatering or treatment, whether sludge is incinerated. From the treated sludge the potential amount of small scale incineration plants needed with 3.5% increased incineration for next year is calculated as follows:

$$X2 = \frac{Vs \times Tr}{365d} \times Ii \div Y \qquad (4)$$

where X2 is amount of incineration plants needed with treated sludge

when Tr = 20%

Y = 100 $\frac{tons}{day}$ treatment

With treated sludge and values of Tr and Y given above, the amount of incineration plants needed is calculated with Formula 4, which gives the estimation of 4,99 (rounded up to 5) incineration plants needed annually.

CONCLUSION

Adding together X1 and X2, the sludge incineration requires approximately six plants to be built annually in China. Assuming every incineration plant requires only a single boiler to incinerate sludge with incineration capacity ranging from 100 tons to 200 tons a day, the following conclusions are created:

In the best case it would require approximately six small scale incineration plants (100 tons of sludge disposed in incineration per day) to be built in China annually.

- During ten year period the incineration plant building includes 29 huge scale plants (200 tons of sludge incinerated a day), whether incineration growth is 3.5% a year.

In the worst case the estimation must also be changed according 3.5% incineration to potential growth during the next 13th FYP. This would represent a potential of three incineration plants with 200 tons of sludge treatment capacity during next FYP.

- During ten year period the incineration plants building includes six huge scale plants (200 tons of sludge incinerated a day), whether incineration growth is 3.5% during one FYP.

9.2 Participants in Sludge Business

The lack of government enforcements and a comprehensive policy have slowed down the sludge business. Sludge discharge has grown 5% annually and rapid building of new wastewater treatment plants has grown the amount of residual sludge. Wastewater industries are using the cheapest method to discharge sludge as landfill or non-dewatered landfill.

The sludge and incineration business depends on four different major factors, as can be seen in Table 6. There are all the stakeholders, which must be taken into account. The most important stakeholders are: technology providers, technology buyers, central government regulators and local level regulators.

Technology providers do co-operation with various stakeholders and develop more efficient water and sludge management solutions to minimize sludge discharge costs from wastewater plants. Providers should contribute more analysis and data to give alternative sludge low cost solutions and reports.

Technology buyers co-operate with technology providers in wastewater and sludge treatment at the design phase to figure out best solutions. Technology buyers can co-operate with the local government to find possible funding to safe sludge treatment in China.

Local level regulators give enforcements to sludge treatment and promote long term environmental friendly cost management. Local regulators set wastewater and sludge treatment fees considering sludge disposal promotion in an economic way.

Central government regulators can give regulations and enforcements on higher efficiency in sludge treatment solutions and strengthen sludge treatment policies. Central government regulators can also promote and invest projects around China to treat sludge more environmentally friendly.

Table 6. Stakeholders in this table. (Lingnan, H. 2011. pp. 36-37.)

Stakeholder	Description	Influence	Impact level	Management strategy
Local authorities	Regional government and communities	Supervision and MSST quality control	High	Keep satisfied
National authorities	Ministries and environmental agencies	Rules and price maker	High	Keep satisfied
Wastewater treatment industry	WWTPs, water utility group	MSST operation	High	Manage closely
Facility supplier	Technology and equipment provider for MSST	MSST capacity improvement	Medium	Manage closely
Service payers	Private & corporate user	Main income for MSST	Low	Keep informed
Sub-contractor	Handling MSST project	Supplement for MSST capacity shortage	Low	Keep informed
Organizations	Institution, Nature protection organization, NGO etc.	MSST research and giving advice	Low	Keep informed
Finance sector	Bank and other financing service companies	Provide financing service for wastewater treatment companies	Medium	Keep informed
Agriculture industry	Sludge Land application	Sludge disposal	Medium	Manage closely
Municipal solid waste management industry	Sludge Co-landfill with MSW	Sludge disposal	Medium	Manage closely

10 THE CHINESE GOVERNMENT AND PROJECTS

"International best practice views sludge as a resource, but in China this is in its infancy, with 80% sent to landfill. New government policies set national goals of treating 70% sludge in large cities and 50% in small cities by 2015. The Chinese government plans to invest RMB 31.2 billion in sewage sludge treatment", (Mark, H. 2013.)

From 2000 to 2010, wastewater collection and treatment has raised from 34% to 70%. Chinese cities are facing challenges because of increasing amount of sludge. The landfill area is getting smaller and smaller, and still huge amount of sludge is dumbed as landfill. The Chinese government wants to support 12th FYP by investing RMB 421 billion to establish wastewater treatments as additional treatment. 7.5% of that (RMB 31.2 billion) will be invested to sewage sludge treatment. The next FYP should represent the same amount of government support. (Mark, H. 2013.)

April 9, 2013 some cities were already planning investing in facilities such as:

- Foshan sludge treatment center – RMB 130 million
- Wuhan 2020 eight sludge disposal centers – RMB 1 500 million
- Shanghai landfill sludge from 86% to 7% by 2020
- 11 Sludge treatment projects in: Bailonggang, Shidongkou, Zhuyuan
- Cement production facilities that are under construction in Bailonggang

The Ministry of Environmental protection (MEP/MOEP), the Ministry of Housing and Urban-Rural Development, P. R. China (MOHURD) and the Ministry of Science and Technology promoted sludge utilization practices by publishing "*Policy on Sludge Treatment and Pollution Prevention Technology in Urban Wastewater Treatment Plant*." These plans showed PRC's support for sludge utilization and for having cleaner future with environmental protection. In 2009 MOEP and MOHURD published regulations and policies such as: "*The Technology Policy of Pollution Prevention and Control for Treatment and Disposal of Sewage Sludge"*. In 2009 MOEP published "*Best Available Techniques Directive for Treatment and Disposal of Sludge from WWTP"*. MOHURD haven't forced any beneficial sludge utilization regulations but it has highly recommended and encouraged to reuse and recover sludge energy resources. (Victoria, B. 2011.)

10.1 Old Projects

There are some potential sludge treatment solutions, but those require high-technology sludge treatment and high investments. There are some small investment projects which have caused failures. The lack of financial aid has caused these problems in the sludge treatment sector. Some projects with problems in sludge processing are listed below. Furthermore in these projects, proper design capacity and cost estimation are keys to successful projects:

- Beijing Cement Plant Green Cement Sludge Treatment
    - This project was top 10 sludge treatment projects in China. The project idea was to turn sludge into cement, but some technical issues have caused quality and environmental problems. This green cement project runs production under its designed capacity with loss.

- Shanghai Shidongkou Sludge Treatment Plant
    - The project is the first full sludge drying incineration plant. The plant started operation in September 2005 and it processes 220 t/d of dry sludge with thickening, dewatering, fluidized bed drying and incineration. The incineration technology comes from ANDRITZ, but the plant operates at half of its designed capacity. Problems resulted from intentionally undersized design in incineration. The experts have estimated also higher sand percentage in sludge which causes higher costs in maintenance.

- Sludge Treatment Plant Guangzhou Gede
    - Guangzhou Gede was intended to process sludge into bricks. The project with Guangzhou Gede and BOT was one of the top projects in the world in 2004. The treatment operation in Guangzhou Gede has halted and it’s storing sludge while requesting aid from the government. The experts have estimated that small equipment capacity, poor management and total capacity have caused failure in this plant.

10.2 Sludge Regulations

In Table 7 it can be seen PRC government sludge regulations that are related to sludge management (Victoria, B. 2011.)

Table 7. Sludge regulations. (Victoria, B. 2011.)

Table 4. List of the active regulations related to sludge manag

Code	Title	Level
GB18918-2002	Pollutants Discharge Standard of Municipal Wastewater Treatment Plant in China	Nationa
CJ247-2007	Sludge Characteristics of Municipal Wastewater Treatment Plant	Minister
CJ/T239-2007	Classification of the Technologies for Sludge Disposal	Minister
Code	**Title**	**Level**
GB4284-84	Pollutants Control Standard of Sludge for Agricultural Application	National
CJ248-2007	Sludge Characteristics of Gardening from Municipal Wastewater Treatment Plant	Ministeri
CJ/T249-2007	Sludge Characteristics of Landfill with Municipal Solid Waste from Municipal Wastewater Treatment Plant Disposal	Ministeri
GB16889-2008	Standard for Pollution Control on the Landfill Site for Domestic Waste	National
-	In preparation	-
-	In preparation	-
-	In preparation	-

11 ENVIRONMENT

"In January 2013 China's government actually banned the use of wastewater and sewage sludge in agricultural use. Reportedly, municipal wastewater contaminated by industrial sources, has resulted in sludge from Chinese treatment plants being too contaminated with toxic chemicals and heavy metals to be reused as fertilizers on land" (Mark, H. 2013.). Untreated sludge causes severe ground water pollution and contains heavy metals, chemicals, pathogens making it not suitable as untreated landfill.

11.1 Energy from Waste

The Central People Government of the People's Republic of China estimates that there are huge opportunities for Energy from Waste (EfW) industries. Until May there are 178 EfW plants in China, with waste disposal capacity of 166,000 tons/day. At the end of current FYP there are 400 EfW plants in China and it is estimated that 1000 EfW plants will be in China in the future. The investment requires RMB 500 billion.

MEP has announced public service projects in MEP's media news:

- 9.2.2015 MEP announced Beijing is struggling against mounting waste and requires three new waste incinerators to burn waste. Incineration will be the major way dealing with waste and Beijing is ready to dig out landfill waste and burn it. Burning the waste reduces 90% of landfill space requirement.

11.2 Sludge Solutions

Many good approaches worldwide are only pilot scale or on small scale projects. But, for example, Hangzhou full scale sewage sludge incineration burns sludge with resultant ash being used by nearby cement plant. This also occurred in Jiaxing sludge incineration plant and the method can be a clever usage of sludge and ash.

Sludge incineration is one of the answers if sludge disposal area as landfill is scarce. Thereby it increases the attractiveness of sludge incineration. Another method is to combine municipal solid waste incineration together with municipal solid sludge incineration. (Asian Development Bank, 2012.)

Incineration Advantages:

- No landfills
- Solid waste volume reduced by 90% and weight by 75%
- Waste-to-energy principle
- Recovers ferrous metals for recycling

Incineration Disadvantages

- High investment costs
- A risk of emission danger for the humans and environment
- Loss of organic substances

For the optimal incineration situation, these are requirements:

- The material has sufficient energy content
- Nearby energy markets
- The facility fits with other MSWM system
- No landfill space making incineration profitable
- Controlled emission air pollution

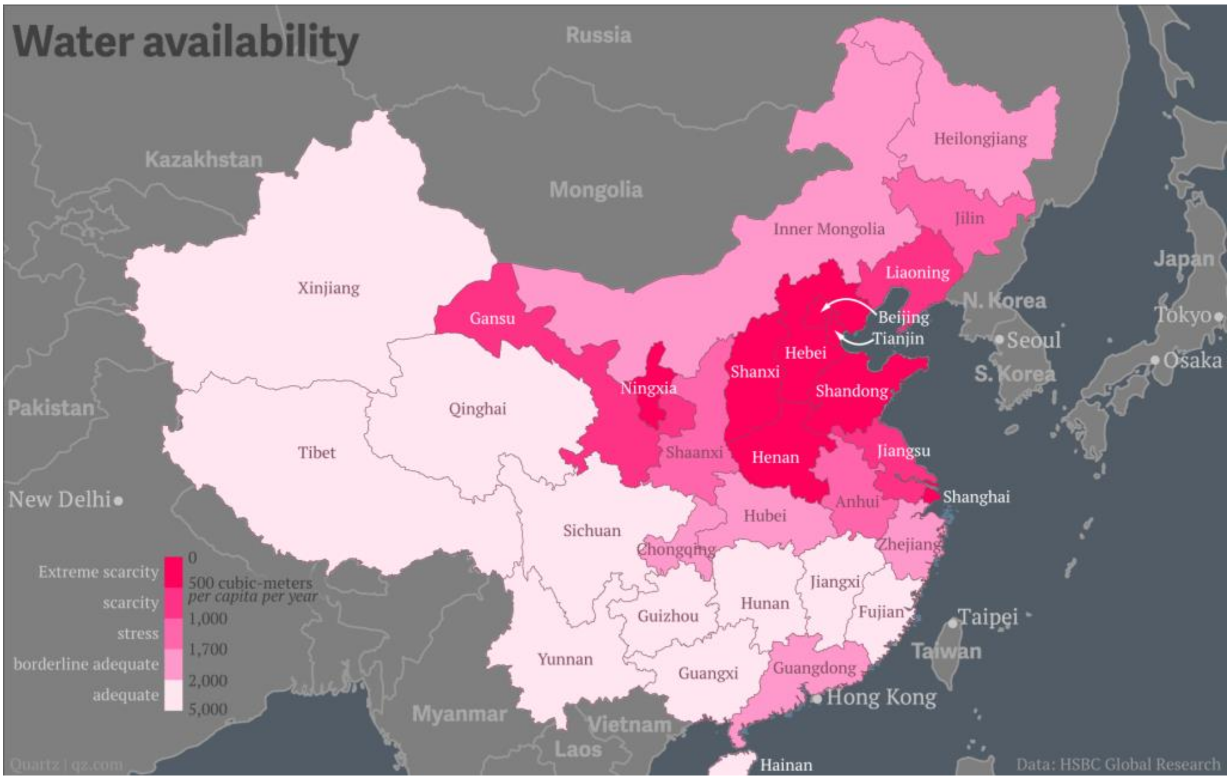


Figure 21. China water scarcity areas 2012. (Water Availability, 2000.)

China water scarcity areas (see figure 21) can be inferred as possible sludge incineration business due to sludge disposal as landfill contaminates soil and land area scarcity makes sludge incineration a fast solution for sludge treatment problems and stops soil contamination. Table 8 shows the sludge technical disposal to represent carbon footprints by different methods. Some areas such as Shanghai are planning to reduce sludge disposal, currently 86% to 7% by 2020. There isn't any confirmation which technology is chosen, but financial support is entirely from Shanghai regional government. The wastewater plants don't have any extra fee in wastewater tariff for sludge disposal; therefore investment must be done by regional government authorities.

11.3 Emission Business

Chinas project aims to improve air quality by 2017 in the entire country. The project's key cities are Beijing, Shanghai and Guangzhou where coal consumption will be controlled. The plan is to increase 2012 – 2017 non-fossil fuels from 9.1% to 13%. (Barbara, F. 2013., Barbara, F. 2014.) The reduction of coal incineration can be a potential sludge drying business as lower coal consumption by offering sludge and coal as auxiliary fuel incineration for energy producing or alternatively fully dried sludge incineration such as Shidongkou sludge incineration plant. Shidongkou WWTP and fluidized bed incineration system have been established in Shanghai 2005. It's the first fully dewatering and drying sludge incineration plant in China. The plant can treat approximately 200 t/d solid sludge to produce heat and electricity.

11.4 Sludge Incineration Emissions

Sludge incineration causes some emissions such as flue gas and different oxides. In Figure 22 it can be seen direct emission effects by sludge drying and incineration. The drying with incineration causes more emission directly than landfill fertilizer disposal.

The most typical emissions incineration causes:

- Nitrogen oxides (NO_x), which depend on local sewage characteristics and are formed in result of oxidation.

- Carbon monoxide (CO), which is formed when insufficient or high amount of oxygen is in incineration reaction. The result is lower temperature and that the combustion isn't pure.

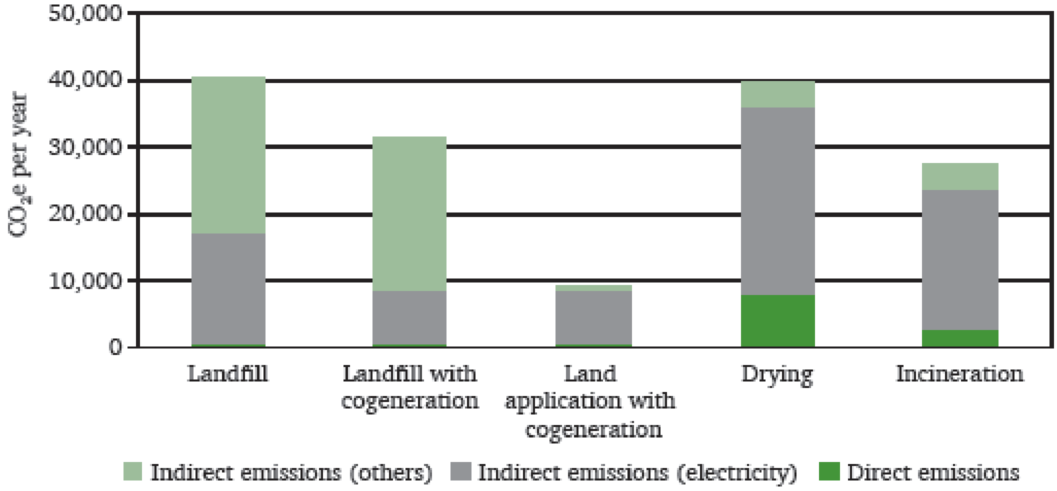
- Sulfur dioxide (SO_2), that is similar to nitrogen oxides. It depends on local sewage characteristics and is formed in result of oxidation.

- Particulate matter, which depends on incinerator, moisture and volatiles.

- Ferrous metals, those are in sludge metal content or volatilizes in incineration.

- Metals, which are typically mercury and heavy metals.

- Hydrocarbons are unburned matters, which are formed as an end result of incineration process. (Solid Waste Disposal, 2010.)



CO_2e = carbon dioxide emissions.
Source: Scanlan, P., H. Elmendorf, A. Shaw, and S. Tarallo. 2009. Evaluating Greenhouse Gas Emissions: An Inventory of Greenhouse Gases is an Important Piece of the Sustainability Puzzle. *Water Environment and Technology.* 21(4). pp. 31–35.

Figure 22. Greenhouse gas emissions of different sludge management options. (Asian Development Bank, 2012.)

Table 8. Sludge carbon footprints with best techniques available. (Asian Development Bank, 2012.)

Reference Number	Technical Route	Carbon Footprint[a]
1	Thermal hydrolysis, anaerobic digestion, biogas utilization, heat drying (10% moisture content), coal substitution (e.g., in a power plant or cement kiln)	(500)
2	Anaerobic digestion, biogas utilization, landfill with landfill gas utilization	0
3	Thermal hydrolysis, anaerobic digestion, biogas utilization, land application	200
4	Anaerobic digestion, biogas utilization, compost, land application	450
5	Anaerobic digestion, biogas utilization, land application	950
6	Heat drying(10% moisture content), coal substitution	1,300
7	Composting, land application	2,400
8	Heat drying, gasification, energy recovery	4,750
9	Lime stabilization, land application	4,900
10	Heat drying, incineration, heat recovery	5,900
11	Landfill with landfill gas utilization	6,200
12	Anaerobic digestion, biogas utilization, landfill without landfill gas management	6,300
13	Heat drying (65% moisture content), land application	7,600
14	Heat drying (40% moisture content), land application	10,000
15	Landfill without landfill gas management	30,000

( ) = negative.
[a] Based on a typical urban wastewater treatment plant treating 100,000 cubic meters/day, producing 80 tons/day of dewatered sludge with 80% moisture content; carbon footprint indicated as tons of carbon dioxide equivalent/year.

11.5 Tracking

There are no continuous data about sludge utilization. The next step for sustainable development and emission reduction is to gather data and records about land application, landfilling and incineration. The database would keep companies and government updated about risk locations and focus more developed disposal methods. Creating the database requires a policy from MOHURD or PRC to make every single WWTP to analyze their disposals and keep them in updated form. In Table 9

PRC's beneficial sludge disposal methods are listed. It's necessary to have strict regulation; otherwise the data creation wouldn't occur in the future. Some sanctions and credits would be applied by this tracking database. Whether disposal is not following PRC or MOHURD tracking policies, the WWP would receive some sanctions. The fear of sanction would keep tracking continuous.

The finance of the sludge tracking data-system is a challenge. Wastewater plants have to raise their fees in order to keep tracking systems alive or alternatively government financing is needed. But the major problem is whether WWPs are ready to increase their fees or whether water consumers are ready to pay more for clean water. In order to develop cleaner future and the sludge tracking data system, the extra fee would be in high demand to keep up the system and maintain it.

Table 9. Sludge treatment comparison on governmental aspect. (Asian Development Bank, 2012.)

	Technical Route	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Processes involved	Thermal hydrolysis	✓		✓												
	Anaerobic digestion	✓	✓	✓	✓	✓							✓			
	Biogas recovery	✓	✓	✓	✓	✓							✓			
	Composting				✓			✓								
	Lime stabilization									✓						
	Heat drying	✓					✓		✓					✓	✓	
	Incineration										✓					
	Gasification								✓							
	Land application			✓	✓	✓		✓		✓				✓	✓	
	Landfill		✓									✓	✓			✓
	Landfill gas use		✓									✓				
	Coal substitution	✓					✓									
Main attributes	Capital costs	H	M	H	L	L	H	L	H	L	H	M	L	H	H	L
	O&M costs	H	M	M	M	L	H	L	H	M	H	M	M	H	H	L
	Land required	L	M	H	H	H	L	H	L	H	L	M	M	M	M	H
	Volume reduction	H	L	L	M	L	H	M	H	L	H	L	L	M	M	L
	O&M capacity	H	M	H	L	L	H	L	H	L	H	M	L	H	H	L
	Energy recovery	Y	Y	Y	Y	Y	Y	N	Y	N	Y	Y	Y	N	N	N
	Other resource use	Y	N	Y	Y	Y	Y	Y	Y	Y	P	N	N	Y	Y	N
	Carbon footprint	L	L	L	L	L	L	M	M	M	M	M	M	H	H	H
	Treatment footprint	H	M	M	M	M	L	H	M	H	M	L	M	L	L	L
	Pathogen free	Y	N	Y	Y	N	Y	Y	Y	N	Y	N	N	Y	Y	N
Suitable for the PRC?		Y	(Y)	Y	Y	Y	(Y)	(Y)	(Y)	(Y)	(Y)	N	N	N	N	N

L = low; M = medium; H = high; Y = Yes; N = no; P = possibly; (Y) = might be justified in specific contexts, or become suitable as result of technical maturity; O&M = operations and maintenance.

Note: "Land required" is for disposal or application. "Other resource use" is beneficial use of nutrients or other resources present in the sludge, for example through direct application to land, in compost, or the production of fertilizer or construction material. "Treatment footprint" is size of land required for treatment facilities. "Pathogen free" is where residual solids are free of pathogens, potentially allowing unrestricted application to land. Refer to Table 8 for description of technical routes 1 to 15.

12 COMPETITION

The 13th FYP should be years 2016-2020 green energy sectors rapid growth. Some Chinese cities are getting boosted by green ecological energy. There is a scope for tens of billions RMB worth growth in environmental protection companies. It has been estimated that the European technology will be exported for Chinese industrial use, because European countries have more advanced technology and higher safety standards. The 13th FYP estimation in China is more focused on increasing wind and solar power, but the problem has been its hard implementation to the huge grid. The sludge incineration has competes with renewable energy sources, but on the other hand sludge incineration gets rid of sludge disposal problems. (Zhang, C., Xu, N. 2014.)

Whether sludge disposal problems as landfill cannot be solved, its incineration comes in high demand due to its high material reduction capacity, which can be up to 90%. Sludge treatment as a fertilizer is becoming a more popular solution, if the Chinese government enforces strict sludge disposal regulations although sludge incineration in huge scale has more beneficial influences including heat and energy recovering. There isn’t exactly an accurate answer for the views of sludge incineration future, but considering money as the most powerful inducement, the sludge disposal shall meet its requirements as incineration with coal as auxiliary fuel. In Appendix 1 is listed the possible coal fired plants which could add sludge as auxiliary fuel, while the Chinese government is reducing coal consumption. This is a business opportunity in China to maintaining energy output as the same. Because coal burning has to be reduced, some alternative fuels must be added and energy production must stay stable. This method isn’t reducing any emission disasters, but utilizes sludge for clever usage. Sludge incineration with coal increases pollutant emissions and requires flue gas cleaning systems compared to fertilizer use. The investment for this is too high and plants are not ready for the costs. Whether emission regulations are strict, sludge disposal shall meet its fertilizer requirements for agricultural use.

12.1 Companies and Sharing

“Capitalizing on global leading market vision, innovativeness, and operation management to lead solid waste industry to prosperity” (Solid waste summit, 2014). Solid waste summit is linking together project owners, technology providers, investors, and developers. Solid waste summit offers knowledge sharing, long term waste management and pollution control by studying legislations and policies in China and around the world. The last meeting “5th solid waste management summit 2014” was held 11-12 June, 2014 in Shanghai. Table 11 and 12 represent wastewater sectors. Those can promote waste water and sludge treatment activities. There is an estimation about more than ten water and sludge treatment companies and more than 20 energy from waste operators in China. (Solid waste summit, 2014.)

According to Environmental Xperts website, there are 152 companies around the world that can both treat sludge and incinerate it. (Environmental Xperts, 2015.) From those 152 companies, Veolia is the most well-known water supply, wastewater, waste management, energy and transport service in China. Since Veolia is the most known company around China it's a huge business competitor in sludge business and incineration markets.

MOP has awarded announcement and praised Veolia's long term relationship with the People's Republic of China and since Veolia claims to be leading water & WWP treatment organization, it can offer these services:

- Physical/Chemical Process (WWP)
- Biological Treatment (WWP)
- Anaerobic Wastewater Treatment (WWP)
- Filtration and Separation (competition with ANDRITZ)
- Headworks (grit and grease removal, screening)
- Extraction (remove hydrocarbons from water)
- Membrane-Based Technologies (membrane systems)
- Evaporation and Crystallization (recover by-products and reduce volume)
- Biosolids and Bioenergy (solar sludge drying, hydrolysis, incineration, competition with ANDRITZ),
- Water Treatment Chemicals (WWP)
- Mobile Water Treatment (WWP).

(Veolia, 2015.)

Table 11. Organizations in wastewater sector, those can promote waste water and sludge treatment activities (Lingnan, H. 2011. p. 24.)

Name	Location	Classification	Homepage	Brief Introduction
Development Center of Water Treatment Technology	Hangzhou, Zhejiang	City level	http://www.chinawatertech.com/english.shtml	·The Development Center of National Liquid Membrane Separation Engineering & Technology Research; ·China production base of liquid separation membranes and modules. ·The backing unit of Chinese Seawater Desalination and Water Reuse Society and Zhejiang Province Membrane Society; ·State Equipping Center of Purifying Water Technology and Equipment; ·State base for research & development, fruit transfer and production of separation membrane, and academic exchange center both at home and abroad.
XuZhou Research Institute of Water Treatment	Xuzhou, Jiangsu	City level	http://www.xzwater.com/en/about.htm	A professional company that specialized in researching and developing various kinds of water treatment technologies. It was founded at 1984, it had supplied about 1000 enterprises nationwide with various kinds of water treatment technical services. Product covers Ion Exchange Resin, Water Treatment Equipment, Water Treatment Medicament, Padding and Fittings of Water Treatment Equipment
China Industrial Water Treatment Research Center	Tianjin	State leve	http://www.ciwt.cn (no English version)	Established with the approval of the Ministry of Science and Technology, dealing with technology research of water treatment, chemical agent production with a capacity of 20000tons/year
Water Treatment and Water Environment Restoration Research Center of the Ministry of Education	Nanjing, Jiangsu	Provincial level	http://hjxy.nju.edu.cn/files/organization/xfzx.htm (No English Version)	Approved by the Ministry of Education, focuses on the technical innovation of wastewater treatment, water restoration and water efficiency.
Chengdu Jini Water Treatment Equipment Research Institute	Chengdu, Sichuan		http://www.chinagenii.com (No English Version)	Belongs to Sichuan Yuyang Environment Engineering Co., Ltd., focuses on research and development of wastewater treatment engineering and equipment. Supplying reverse osmosis membrane water treatment equipment, buried sewage treatment equipment, water reclamation equipment and integrated service
Nanjing Water Treatment Engineering Technology Center	Nanjing, Jiangsu	City level	http://www.njust.edu.cn/site/huayuan/zhongxing5.htm	Research fields: chlorine dioxide for sanitary water and wastewater treatment; corrosion and scale inhibitors and bactericidal algicide deal for recycle water; cationic polyquaternium for sanitary water, wastewater and sludge dewatering; dealing with waste water difficult to degrade, slightly polluted water

Table 12. Universities in wastewater sector, those can promote waste water and sludge treatment activities (Lingnan, H. 2011. p. 25.)

Name	Location	Homepage	Brief Introduction
Department of Environmental Science and Engineering, Tsinghua University	Beijing	http://env.tsinghua.edu.cn/Eng/Research	Wastewater treatment and reclamation • High efficient bioreactors and their principles • Membrane bioreactor and fouling control • Energy-saving N and P removal processes • Novel processes based on molecular biological theory • Eco-technologies and enhanced principles
College of Environmental Science and Engineering, Tongji University	Shanghai	http://sese.tongji.edu.cn/College/english	Its Institute of Water Environment Rehabilitation s now focusing on the following research fields: the mathematical and physical modeling of surface water environment and ecological water treatment process; the ecological treatment engineering technologies of agricultural production and rural domestic pollution; regional environment planning, environmental standards and policies.
School of the Environment, Nanjing University	Nanjing, Jiangsu	http://hjxy.nju.edu.cn/en_wbe/eng	• High-concentrated and Hard-degraded Toxic and Organic Waste Water Treatment • Clean Production Technology • Waste Water Treatment Project • Stratagem on Water Pollution Control
Nanjing University of Science and Technology	Nanjing, Jiangsu	www.njust.edu.cn	Please refer to Nanjing Water Treatment Engineering Technology Center in Table 4, which is affiliated to NJUST
Wuhan University	Wuhan Hubei	http://sdsy.whu.edu.cn/sdxy	Owns 1 State Key Laboratory of Water Resources and Hydropower Engineering science and 4 provincial key laboratory
College of Environmental and Resource Sciences, Zhejiang University	Hangzhou, Zhejiang	http://www.cers.zju.edu.cn/	The school owns the Key Lab of Ministry of Education (Laboratory of Remediation of Polluted Environment and Ecological Health), and the Research Center of Environmental Technology. Research Center of Membrane and Water Treatment is affiliated to Zhejiang University, please refer to Table 4

13 PATENT IDEA

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13.1 Background Research About Patent

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14 CONCLUSION

Lack of financial support has slowed down sludge incineration markets in China. In the future even more sludge is produced by growing urbanization and PRC has to react it somehow. Sustainable sludge treatment solutions are becoming highly demanded in the future. Sludge incineration is one of the potential answers for a fast solution in urban areas. Sludge incineration markets are growing slowly and only small part of the sludge is treated and incinerated for energy. Potential customers for sludge incineration business are hard to find, but following up and keeping up to date the People's Republic of China government's Five-Year Plan will increase the chances to find possible sludge incineration markets.

Some potential methods to dispose sludge are cement kiln incineration and green cement utilizing. Since China's population and urbanization is highly growing it causes even more sludge and the requirements to build more buildings and so the demand of producing cement is growing. On the other hand some cement plant's green cement projects have failed due to quality problems, high investments and sludge drying requirements.

The high demand of lowering landfill sludge and water pollution in China makes sludge business a good and fast solution. On the other hand, sludge incineration is not the most environmentally friendly solution and cleaner disposal methods can be acquired, such as sludge disposal as fertilizer. There is a possibility to burn sludge as auxiliary fuel with coal, since China is lowering coal consumption radically and dry sludge can be used to fill fuel requirements. There are some side-effects of sludge incineration with coal, which require flue gas cleaning systems and those are high cost investments. Plants are not ready to invest to cleaning systems. Therefore it's hard to predict, which is the direction PRC is forcing sludge disposal to enforce with regulations.

Continuous data gathering, monitoring and recording system is necessary to develop sustainable sludge disposal methods. MOHURD's next step should be to form a data analyzing team, develop a sludge disposal database or ordain a sludge disposal tracking policy. The development of the sludge disposal data-system would create potential projects for ANDRITZ in the future and keep the company updated about sludge disposal values. The major problem in this case is the regulation inception. It can be only ordained by the Ministry of Housing Urban-Rural Development and People's Republic of China.

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Appendix 1. COAL POWER PLANTS IN CHINA – 2015 March 1. (Wikipedia, 2015.)

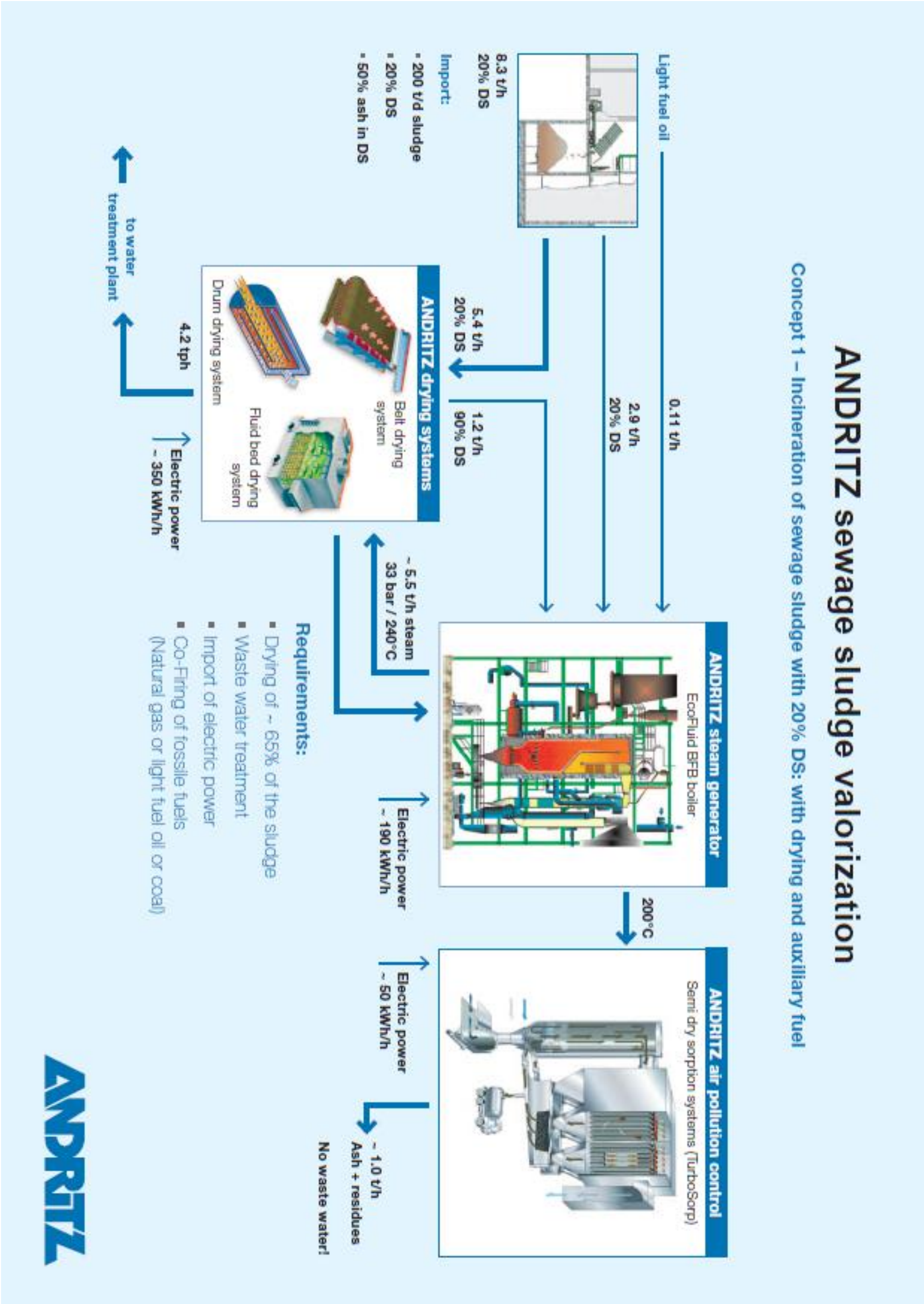
Station	Chinese Name	Province	Total Capacity (MW)	Units and Status	Operator(s)	Coordinates
Luohe Power Station	洛河电厂	Anhui	2,400	4*300, 2*600 operational	Datang	32°41′07″N 117°04′40″E
Pingwei Power Station	平圩电厂	Anhui	2,400	4*600, operational		32°41′03″N 116°54′05″E
Tongling Power Station	铜陵电厂	Anhui	2,975	2*300, 2*660, 1*1,055 operational	Wanneng	30°53′30″N 117°45′00″E
Luohuang Power Station	珞璜电厂	Chongqing	2,600	4*350, 2*600 operational		29°20′55″N 106°26′05″E
Fuzhou Power Station	福州电厂	Fujian	2,720	4*350, 2*660 operational	Guodian	25°59′27″N 119°28′54″E
Houshi Power Station	后石电厂	Fujian	4,200	7*600 operational	Huayang Group	24°18′11″N 118°07′35″E
Kemeng Power Station	可门电厂	Fujian	2,400	4*600 operational	Huadian	26°22′24″N 119°45′44″E
Ningde Power Station	宁德电厂	Fujian	2,520	2*600, 2*660 operational	Datang	26°45′27″N 119°44′13″E
Jingyuan Power Station	靖远电厂	Gansu	2,150	4*220, 1*300, 2*330, 1*340 operational	Guodian	36°43′46″N 104°45′37″E
Pingliang Power Station	平凉电厂	Gansu	2,400	4*300, 2*600 operational	Huaneng	35°30′06″N 106°47′10″E
Huilai Power Station	惠来电厂	Guandong	3,200	2*600, 2*1,000 operational	Guangdong Yuedian	23°00′20″N 116°32′48″E
Sanbaimeng Power Station	三百门电厂	Guandong	3,200	2*600, 2*1,000 operational	Datang	23°33′58″N 117°05′49″E
Haimeng Power Station	海门电厂	Guangdong	2,060	2*1,030 operational	Huaneng	23°11′17″N 116°39′14″E
Pinghai Power Station	平海电厂	Guangdong	2,060	2*1,030 operational	Guangdong Yuedian, Zhujiang Investment	22°36′32″N 114°44′34″E
Shajiao Power Station	沙角电厂	Guangdong	3,880	3*210, 2*300, 2*350, 3*660 operational		22°44′50″N 113°40′39″E
Taishan Power Station	台山电厂	Guangdong	5,000[2]	5*600, 2*1000 operational	Guohua Group	21°52′00″N 112°55′22″E

Zhanjiang Power Station	湛江电厂	Guangdong	2,400	4*300, 2*600 operational	Zhanjiang Electricity	21°18′35″N 110°24′34″E
Zhuhai Power Station	珠海电厂	Guangdong	2,600	2*600, 2*700MW operational	Yuedian	21°58′04″N 113°10′56″E
Hezhou Power Station	贺州电厂	Guangxi	2,090		2*1,045	24°44′15″N 111°21′09″E
Xibaipo Power Station	西柏坡电厂	Hebei	2,400	4*300, 2*600 operational		38°14′45″N 114°13′09″E
Zhangjiakou Power Station	张家口电厂	Hebei	2,400	8*300 operational	Datang	40°39′28″N 114°56′42″E
Shuangyashan Power Station	双鸭山电厂	Heilongjiang	2,030	1*200, 3*210, 2*600, operational	Guodian	46°33′55″N 131°40′18″E
Shouyangshan Power Station	首阳山电厂	Henan	2,240	2*220, 2*300, 2*600 operational	Datang, Huarun	34°43′53″N 112°45′21″E
Xiangfan Power Station	襄樊电厂	Hubei	2,400	4*300, 2*600 operational	Huadian	31°54′57″N 112°10′10″E
Yangluo Power Station	阳逻电厂	Hubei	2,400	4*300, 2*600 operational	Huaneng	30°41′38″N 114°32′35″E
Jianbi Power Station	谏壁电厂	Jiangsu	3,980[3]	6*300, 2*1000 operational	Guodian	32°10′54″N 119°34′35″E
Ligang Power Station	利港电厂	Jiangsu	2,600	4*350, 2*600 operational		31°56′22″N 120°04′54″E
Taicang Harbor Power Station	太仓港电厂	Jiangsu	2,770	2*135, 2*320, 2*330, 2*600 operational	Golden Concord	31°35′05″N 121°15′25″E
Taizhou Power Station	泰州电厂	Jiangsu	2,000	2*1,000 operational	Guodian	32°11′14″N 119°54′59″E
Yangzhou No2 Power Station	扬州第二电厂	Jiangsu	2,400	4*600 operational	Huaren	32°16′12″N 119°25′19″E
Fengcheng Power Station	丰城电厂	Jiangxi	2,400	4*300, 2*600 operational	Guodian	28°11′45″N 115°42′31″E
Suizhong Power Station	绥中电厂	Liaoning	3,600	2*800, 2*1,000 operational	Shenghua Energy	40°04′48″N 120°00′27″E
Tuoketuo Power Station	托克托电厂	Neimenggu	5,400[4][5][6]	8*600, 2*300 operational, 2*600 under construction	Datang Group	40°11′49″N 111°21′52″E
Yimin Power Station	伊敏电厂	Neimenggu	2,200	2*500, 2*600 operational	Huaneng	48°33′01″N 119°46′40″E

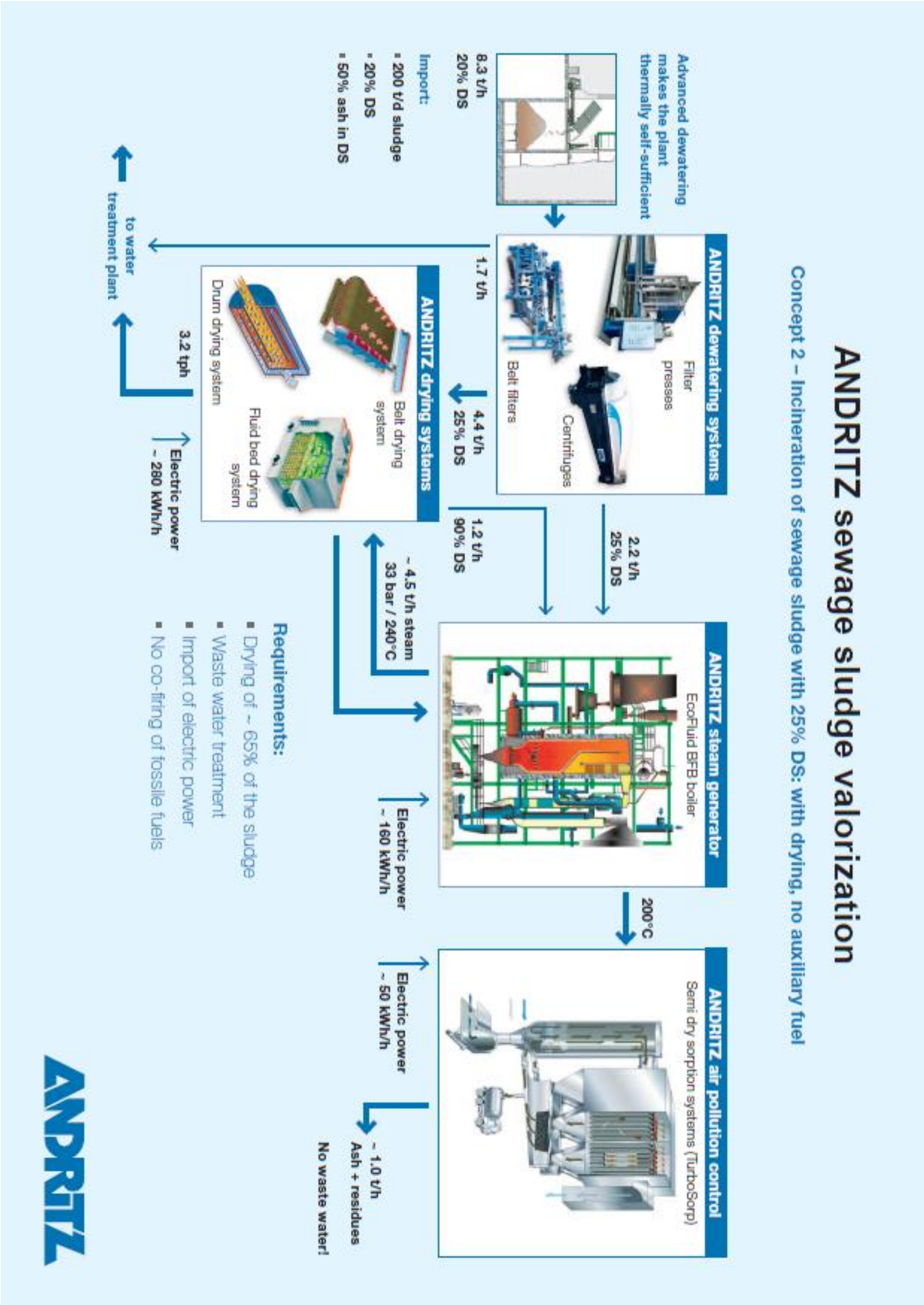
Yuanbaoshan Power Station	元宝山电厂	Neimenggu	2,100	1*300, 3*600 operational		42°18′12″N 119°19′45″E
Dezhou Power Station	德州电厂	Shandong	2,520	4*300, 2*660 operational	Huaneng	37°27′07″N 116°14′35″E
Zouxian Power Station	邹县电厂	Shandong	4,400	4*335, 2*600, 2*1000 operational	Huadian Group	35°19′36″N 116°56′02″E
Caojing Power Station	漕泾发电厂	Shanghai		2*1000 operational	Shanghai Electric	
Shidongkou Power Station	石洞口发电厂	Shanghai		1*320, 3*300, 2*600, 2*660 operational	Huaneng Power International	
Waigaoqiao Power Station	外高桥电厂	Shanghai	5,000	4*300, 2*900, 2*1000 operational	China Power Investment	31°21′21″N 121°35′50″E
Wujing Power Station	吴泾电厂	Shanghai	2,075	1*100, 1*125, 2*300, 1*50, 2*600 operational		31°03′31″N 121°27′56″E
Datong No2 Power Station	大同第二电厂	Shanxi	3,720	6*200, 2*600 operational, 2*660 under construction	Guodian	40°01′44″N 113°17′37″E
Shentou No1 Power Station	神头第一电厂	Shanxi	1,300	2*50, 6*200 operational		39°22′08″N 112°33′19″E
Shentou No2 Power Station	神头第二电厂	Shanxi	2,000	4*500 operational	State Grid Energy Development Co.	39°22′04″N 112°32′00″E
Yangcheng Power Station	阳城电厂	Shanxi	4,620[citation needed]	6*350, 2*600 operational, 2*660 under construction	Datang Group	35°28′11″N 112°34′41″E
Guang'an Power Station	广安电厂	Sichuan	2,400	4*300, 2*600 operational	Huadian	30°31′41″N 106°49′34″E
Panshan Power Station	盘山电厂	Tianjin	2,200	2*500, 2*600 operational	Datang, Guohua	39°58′55″N 117°27′40″E
Beilun Power Station	北仑电厂	Zhejiang	5,000[1]	5*600, 2*1000 operational,	Guodian Group	29°56′26″N 121°48′48″E
Jiaxin Power Station	嘉兴电厂	Zhejiang	5,000[citation needed]	2*300, 4*600, 2*1000 operational	Zhejiang Jiahua	30°37′47″N 121°08′46″E

Ninghai Power Station	宁海电厂	Zhejiang	4,400	4*600, 2*1,000 operational	Guohua	29°29′16″N 121°30′34″E
Wushashan Power Station	乌沙山电厂	Zhejiang	2,400	4*600, operational	Datang	29°30′22″N 121°39′51″E
Yuhuan Power Station	玉环电厂	Zhejiang	4,000	4*1,000 operational	Huaneng	28°06′57″N 121°08′16″E

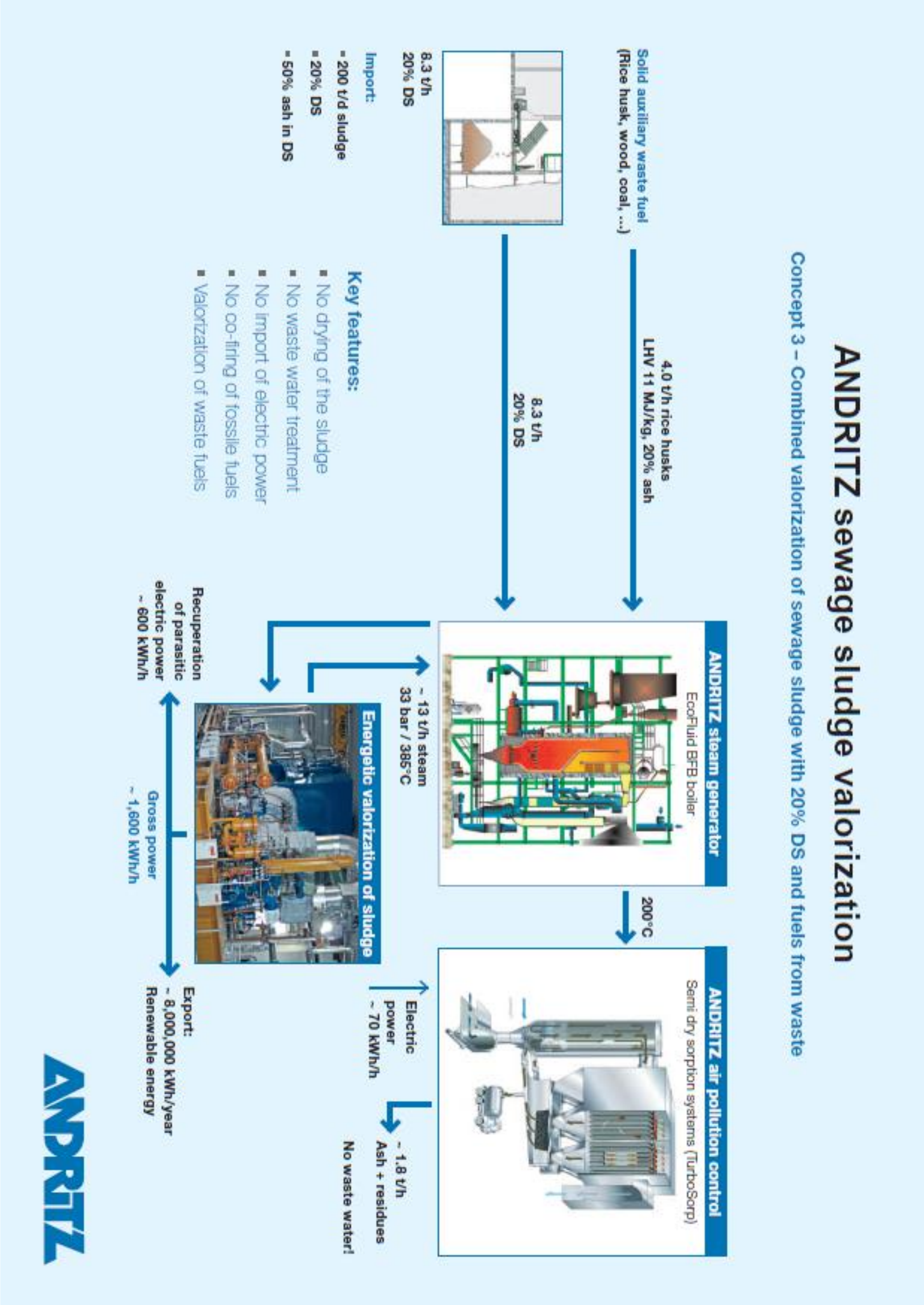
Appendix 2. (Leaflet Concept 1. 2015)



Appendix 3. (Leaflet Concept 2. 2015)



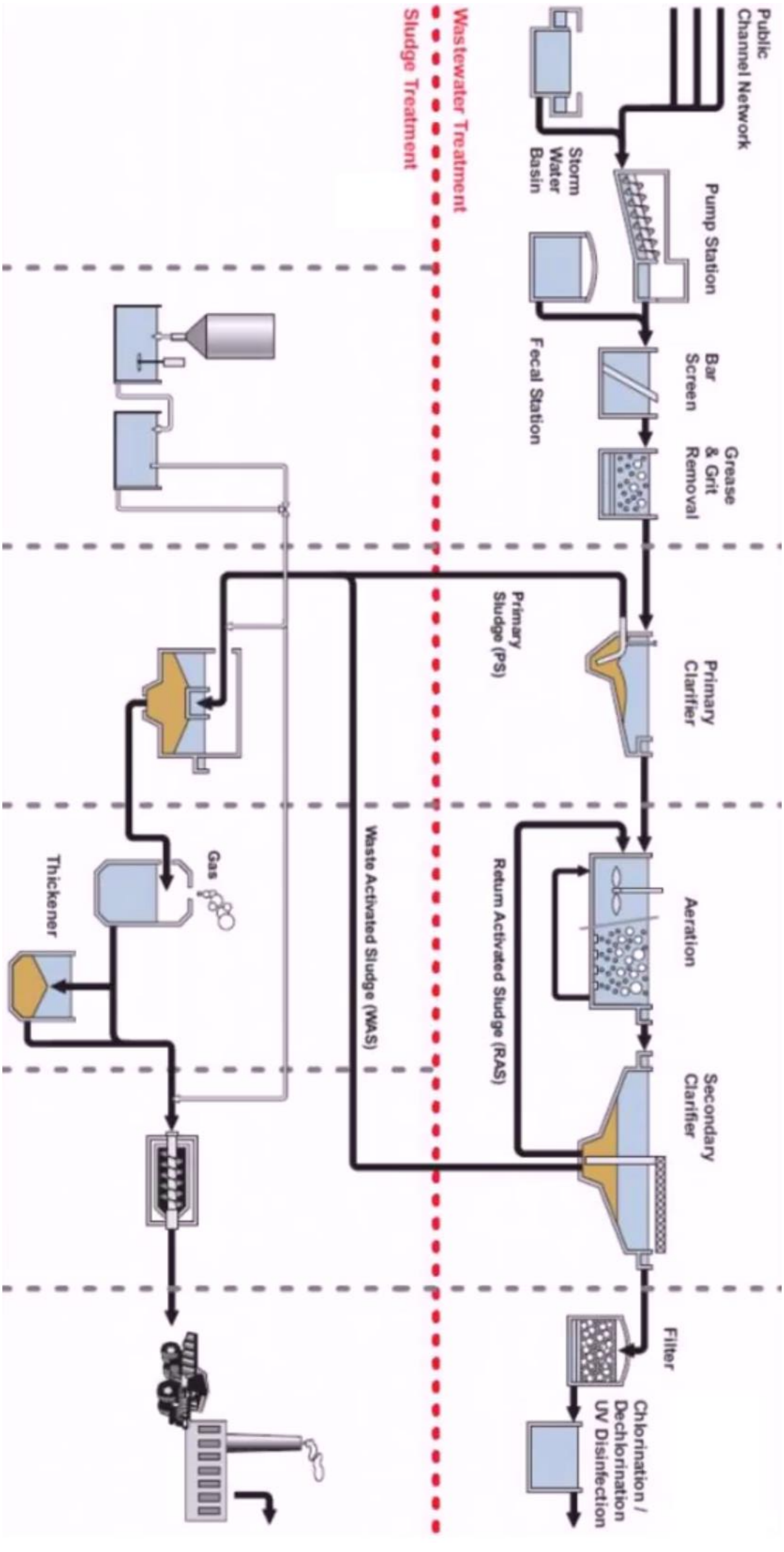
Appendix 4. (Leaflet Concept 3. 2015)



Appendix 5. Heat values of various fuels. (World Nuclear Association, 2010).

	Heat value	% carbon	CO2
Hydrogen	121 MJ/kg	0	0
Petrol/gasoline	44-46 MJ/kg		
	32 MJ/l		
Diesel fuel	45 MJ/kg		
	39 MJ/l		
Crude oil	42-44 MJ/kg	89	70-73 g/MJ
	37-39 MJ/l		
Methanol	20 MJ/kg	37	
	18 MJ/L		
Liquefied Petroleum Gas (LPG)	49 MJ/kg	81	59 g/MJ
Natural gas (UK, USA, Australia)	38-39 MJ/m3	76	51 g/MJ
Natural gas (Canada)	37 MJ/m3		
Natural gas (Russia)	34 MJ/m3		
Natural gas as LNG (Australia)	55 MJ/kg		
Hard black coal (IEA definition)	>23.9 MJ/kg		
Hard black coal (Australia & Canada)	c 25.5 MJ/kg	67	90 g/MJ
Sub-bituminous coal (IEA definition)	17.4-23.9 MJ/kg		
Sub-bituminous coal (Australia & Canada)	c 18 MJ/kg		
Lignite/brown coal (IEA definition)	<17.4 MJ/kg		
Lignite/brown coal (Australia, electricity)	c 10 MJ/kg	25	1.25 kg/kWh
Firewood (dry)	16 MJ/kg	42	94 g/MJ
Natural uranium, in LWR (normal reactor)	500 GJ/kg	0	0
Natural uranium, in LWR with U & Pu recycle	650 GJ/kg	0	0
Natural uranium, in FNR	28,000 GJ/kg	0	0
Uranium enriched to 3.5%, in LWR	3900 GJ/kg	0	0

Appendix 6. (SSWM, 2014).



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